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A spatial computable general equilibrium model for EU regions and sectors

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FOREWORD

The present version of RHOMOLO is the result of a long collaboration between the Directorate-General Joint Research Centre and the Directorate-General for Regional and Urban Policy. They use model simulations for an exploration of the options for Cohesion Policy and for impact assessments. Results of illustrative simulations with an earlier version, in tandem with results from the QUEST model, have appeared in the 5th and 6th Cohesion Reports. RHOMOLO-v2 is going to be used also by the European Investment Bank for an assessment of the impact of EU investment support policies.

The conceptual and mathematical foundations of RHOMOLO have been laid out in a number of reports and background papers by different authors, however none of which was fully aligned with RHOMOLO v1 as it was used in simulations. To some degree, the same is true for the dataset, to which several shortcuts were applied to make it fully consistent with the model. All this is perfectly acceptable in the development phase of a model, but needs to be remedied before the model and its data are made available to new users.

The present report is the results of a painstaking effort to bring the description of RHOMOLO-v2 and the construction of the data fully in line with the coding of the model. Its main authors are Jean Mercenier, Francesco Di Comite and d'Artis Kancs. Major contributions in the form of identification of modelling ideas, sections written, construction of datasets, literature review and alignment of the model code and data are made by María Álvarez-Martínez, Andries Brandsma, Olga Diukanova, Patrizio Lecca, Philippe Monfort, Montserrat López-Cobo, Damiaan Persyn, Alexandra Rillaers, Mark Thissen, Wouter Torfs. The project has also benefited from comments, suggestions and contributions from Stefan Boeters, Johannes Broecker, Leen Hordijk, Artem Korzhenevych, Hans Lofgren, Jesús López-Rodríguez, Fabio Manca, Lesley Potters, Marek Przeor, Robert Stehrer, Kim Swales, Attila Varga, Janos Varga, Toon Vandyck and Marcin Wolski. Finally, we are grateful to the participants of the RHOMOLO Regional Modelling Workshops in December 2013, 2014 and 2015 for their useful feedbacks and remarks on the model and to the heads of unit overseeing the development of the project: Xabier Goenaga Beldarrain and Alessandro Rainoldi.

Needless to say, no model description will be perfect and the consideration of modifications, extensions and improvements will not stop with this publication. This is a live document and all suggestions for improvement are welcome. In addition, the interested reader is invited to use this report as a starting point and feel free to make any enquiry on the status of the model and its further development or visit the RHOMOLO project webpage (https://ec.europa.eu/jrc/en/rhomolo), the RHOMOLO web-tool to get acquainted with the model (http://rhomolo.jrc.ec.europa.eu/) or Joint Research Centre's Regional Economic Modelling thematic page (http://ec.europa.eu/jrc/en/research-topic/regional-economic-analysis-and-modelling).

ABSTRACT

This report presents the current version of the European Commission's spatial computable general equilibrium model RHOMOLO, developed by the Directorate-General Joint Research Centre (DG JRC) in collaboration with the Directorate-General for Regional and Urban Policy (DG REGIO) to undertake the ex-ante impact assessment of EU policies and structural reforms. The RHOMOLO model has been used with DG REGIO for the impact assessment of Cohesion Policy, and with the European Investment Bank for impact assessment of EU investment support policies.

The structure of the model departs from standard computable general equilibrium models in several dimensions. First, it generalises the modelling of market interactions by introducing imperfect competition in products and labour markets. Second, it exploits the advantages of a full asymmetric bilateral trade cost matrix for all EU regions to capture a rich set of spatial market interactions and regional features. Third, it acknowledges the importance of space also for non-market interactions through an inter-regional knowledge spill-over mechanism originating from research and development activities within a country.

This report describes the theoretical foundation of RHOMOLO-v2 (v2 = version 2), its mathematical structure, dynamics, data sources and calibration to allow the reader to approach the model and its outputs with a higher degree of awareness of its strength and limitations. Indeed, as for any general equilibrium model with a reasonable level of complexity, in RHOMOLO it is often challenging to track the mechanisms at work after a policy shock and clearly disentangle causes and effects because of the high number of channels of adjustment and the presence of many feedback effects. The purpose of this documentation is thus to provide a compass to the reader to sail safely through its many equations, assumptions and connections.

JEL classification: C68, D58, F12, R13, R30.

Keywords: Spatial computable general equilibrium, economic modelling, spatial anamysis, policy impact assessment, economic geography, regional economics.

1 INTRODUCTION

RHOMOLO is a spatial computable general equilibrium model of the European Commission, developed by the Directorate-General Joint Research Centre (DG JRC) in collaboration with the Directorate-General for Regional and Urban Policy (DG REGIO) to support the EU policy makers providing sector-, region- and time-specific simulations on investment policies and structural reforms. The RHOMOLO model has been used with DG REGIO for the impact assessment of Cohesion Policy and structural reforms, and with the European Investment Bank for impact assessment of EU investment support policies. RHOMOLO provides.

Since the start of the project, DG REGIO has been the main client of RHOMOLO's output. A first set of simulation exercises have been undertaken in 2010 to assess the impact of Cohesion Policy for the 2007-2013 Programming Period. These illustrative RHOMOLO- simulation results were included in the 5th Cohesion Report. In 2014, RHOMOLO was used for ex-ante impact assessment of Cohesion Policy interventions for the 2014-2020 Programming Period. In tandem with the QUEST model, RHOMOLO provided detailed simulation results by type of Cohesion Policy intervention, a time profile of expected impact, and growth spill-overs between the regional economies of Member States. These RHOMOLO simulation results were published in the 6th Cohesion Report.

RHOMOLO-v2 currently covers the 267 NUTS2 regions of the EU27 and each regional economy is disaggregated into five NACE Rev. 1.1 sectors (agriculture; manufacturing and construction; business services; financial services and public services) and one national R&D sector. Goods and services are either produced by perfectly competitive or by monopolistically competitive firms and consumed by households, governments and firms. Spatial interactions between regions are captured through trade of goods and services (subject to trade costs), capital mobility, interregional investments and knowledge spill-overs. This makes RHOMOLO-v2 particularly well suited for analysing policies related to infrastructures, investments, human capital and innovation.

The present report details the conceptual framework, mathematical structure, dynamics, data sources, calibration and empirical implementation of the RHOMOLO-v2 model. Section 2 introduces the theoretical foundations of the RHOMOLO-v2 model; section 3 delineates its mathematical structure; section 4 describes the data sources, followed by a section on calibration (section 5); section 6 concludes.

Needless to say, RHOMOLO is expected to start evolving from the very moment in which this report will be delivered. It would then be advisable for the interested reader to use this report as a starting point, but to feel free to address to the authors of the report any enquiries on the status of development of the model in the future.

2 THEORETICAL FOUNDATIONS OF RHOMOLO-V2

2.1 THE UNDERLYING GENERAL EQUILIBRIUM FRAMEWORK

In the tradition of Computable General Equilibrium (CGE) models, RHOMOLO relies on an equilibrium framework à la Arrow-Debreu where supply and demand depend on the system of prices. Policies are introduced as shocks; the system changes with optimal supply and demand behaviours adjusting, and the allocation and the supporting price system evolving towards a new equilibrium. RHOMOLO, as all CGE models, therefore provide an evaluation of the interaction effects between all agents through markets, imposing full consistency.

Given the regional focus of RHOMOLO, a particular attention is devoted to the explicit modelling of spatial linkages, interactions and spillovers between regional economies. For this reason, models such as RHOMOLO are referred to as Spatial Computable General Equilibrium (SCGE) models.

Each region is inhabited by households aggregated into a representative agent with preferences characterised by love for variety à la Dixit-Stiglitz (1977). Households derive income from labour (in the form of wages), physical capital (profits and rents) and other financial assets, as well as from government transfers (national and regional); factors may or may not move freely between regions. A part of the disposable income of households is saved, the rest is used for consumption.

Firms in each region produce goods that are sold in all regions to be consumed by households and governments, or used by other firms - in the same or in other sectors - as an input in their production processes. Transport costs for trade between and within regions are assumed to be of the iceberg type and are sector- and region-pair specific. This implies a 5 x 267 x 267 asymmetric trade cost matrix derived from the European Commission's transport model TRANSTOOLS (see Brandsma and Kancs 2015; Brandsma et al., 2015).[6]

2.2 PRODUCT MARKET IMPERFECTIONS

The sectors of the economy are split into two types: perfectly competitive sectors producing homogeneous goods and imperfectly competitive sectors supplying differentiated goods.

Perfectly competitive sectors are characterised by undifferentiated commodities produced under constant returns to scale. In these sectors consumers can differentiate goods only by geographic origin – the standard Armington assumption – but they cannot distinguish individual providers of the good, which means that firms compete under perfect competition and the resulting price equals the marginal costs of production and does not yield any operating profits to the producers.

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[6] http://energy.jrc.ec.europa.eu/transtools/

Other sectors operate under imperfect competition. Here, firms are assumed to produce horizontally differentiated varieties of goods, under increasing returns to scale. Customers identify both the geographic origin of the good and the characteristics associated with each individual product variety, and benefit from this variety either in utility (consumers) or in productivity (firms). Customers' and firms' perception of heterogeneity between variety pairs is captured by an elasticity of substitution parameter, which is the same for all variety-pairs. Their relative preference for one variety over the others is captured by share parameters calibrated on observed consumption patterns.

Regional markets are assumed to be segmented, which implies that firms can optimally choose a different price in every regional market served. Under standard (i.e. large group) monopolistic competition assumptions, in models where preferences/technologies are described in terms of constant elasticity of substitution utility/production functions à la Dixit-Stiglitz/Ethier, the elasticity of substitution would suffice to determine the mark-ups and pricing of each firm in every destination market. Firms would apply the same Free On Board (FOB) export prices to all destination markets, including a constant mark-up that depends only on the elasticity of substitution, and difference in observed Cost, Insurance and Freight (CIF) import prices depend only on differences in iceberg transport costs, abstracting from taxes and subsidies. However, in RHOMOLO-v2, the number of firms in each sector-region is empirically estimated using Herfindahl concentration indices, assuming that all the firms within one region are symmetric (that is, they share the same technology and have identical market shares) and thus have non- negligible market shares, varying in each market served. For this reason, RHOMOLO-v2 adopts a more general description of market structure than the standard monopolistic competition and takes into account this additional element of market power, following Mercenier (1995a, 1995b). The small-group assumption also implies that Bertrand and Cournot competition need not yield identical results: the two options for the imperfectly competitive game are built into RHOMOLO-v2. This market structure implies that, in determining their equilibrium prices or quantities, firms take into account their impact on the price index, which grows with their market share.

2.3 LABOUR MARKET IMPERFECTIONS

Unemployment in RHOMOLO-v2 is modelled through a wage curve. Blanchflower and Oswald (1995) describe the wage curve as 'empirical law' that negatively relates individual real wages to the local unemployment rate (controlling for a set of interpersonal productivity characteristics, such as education, sex, age, etc.). Its existence has been extensively documented in the literature. From a theoretical perspective, the wage curve can be understood as a reduced-form representation of various complete structural models of imperfect labour markets, such as union wage bargaining models, efficiency wage models, or matching models. A wage curve implies that wages are set above the market clearing level, resulting in unemployment. This reduced form representation is extremely appealing in particular when the model's dimension is large, as is the case for RHOMOLO-v2.

Two different types of wage curves are considered in RHOMOLO, a static version that links current unemployment to the wage level and a dynamic extension, which accounts for the impact of past wages, changes in consumption prices and unemployment.

Additional channels of labour market adjustment, such as labour migration, participation, human capital accumulation, etc. are elaborated in a specific labour market module that can be activated or not, as described elsewhere (see Brandsma et al., 2014; and Persyn et al., 2014): hence, we shall not replicate that description here.

2.4 R&D AND INNOVATION

In RHOMOLO-v2 "R&D and innovation" is one specific differentiated-product sector operating with increasing returns to scale technologies. It is special in that innovation is produced by a national R&D sector populated by firms using only high-skill workers with specific skills, hired from a nationally integrated market, hence remunerating these workers at the same nation-wide wage. In addition, the national R&D sector sells its innovation services exclusively as an intermediate input to firms in all sectors within the same country only.

One of the key modelling issues with R&D is that of spillovers. As noted by Leahy and Neary (2007), any innovative activity has an information component that is almost completely non-appropriable and costless to acquire. Though this idea goes back at least to Marshall, its introduction in general equilibrium models is quite recent, either splitting research activities into an appropriable and non-appropriable knowledge (e.g. Goulder and Schneider, 1999 or Diao et al., 1999), or using a product variety extension mechanism à la Romer (1990), Grossman and Helpman (1991) or Aghion and Howitt (1992).

In RHOMOLO, there are spatial technology spill-overs in the sense that the national R&D sector affects the total factor productivity of regional economies within each country, which results in inter-regional knowledge spillovers from the stock of nationally accumulated knowledge. Therefore, the production of R&D services is associated with a positive externality. This positive externality, derived from the accumulation of a knowledge stock in the country, benefits all regions (possibly to a different extent) through sector and region specific knowledge spill-over elasticities.

2.5 NEW ECONOMIC GEOGRAPHY FEATURES OF THE MODEL

The structure of the RHOMOLO-v2 model can engender different endogenous agglomeration and dispersion patterns of firms, by making the number of firms in each region endogenous (see Di

Comite and Kancs, 2014). Three effects drive the mechanics of endogenous agglomeration and dispersion of economic agents: the *market access effect*, the *price index effect* and the *market crowding effect*. The market access effect captures the fact that firms in central regions are closer to a large number of customers (in the sense of lower iceberg transport costs) than firms in peripheral regions. The price index effect captures the impact of having the possibility of sourcing cheaper intermediate inputs because of the proximity of suppliers and the resulting price moderation because of competition. Finally, the market crowding effect captures the idea that, because of higher competition on input and output markets, firms can extract smaller mark-ups from their customers in central regions. Whereas the first two forces drive the system of regional economies towards agglomeration by increasing the number of firms in core regions and decreasing it in the periphery, the third force causes dispersion by reducing the margins of profitability in the core regions.

RHOMOLO-v2 contains three endogenous potential location mechanisms that can contribute to induce the agglomeration and dispersion of firms and workers: the mobility of capital, the mobility of labour, and vertical linkages. Capital is imperfectly mobile between regions hence contributing to reduce differences in rental prices of capital within Europe with capital earnings being repatriated by the households in its region of origin (as in the Martin and Rogers (1995) foot-loose capital model). Workers could be spatially mobile as in Krugman (1991), not only producing in the region where they settle, but also spending their income there, with migration decisions made by considering differences in expected real consumption wages.[7] Finally, all firms in RHOMOLO-v2 share the vertical linkage framework highlighted by Venables (1996) to be source of agglomeration effects.

2.6 SOLVING THE MODEL: INTER-TEMPORAL ISSUES

Due to its high dimensionality implied by its extensive regional disaggregation - RHOMOLO-v2 can include more than one million equations, depending on the chosen options - the dynamics have to be kept relatively simple: expectations are assumed myopic, and it is solved sequentially period after period with stocks being upgraded at the beginning of each year. This implies among other things, exogenous savings rates, inefficient asset markets, and exogenous enforcement of inter-temporal budget constraints.

The code is written in the GAMS language as a system of nonlinear equations, and equilibria are computed mainly using the solver CNS.

[7] Labour mobility between regions is implemented in a specialised labour market sub-module, which is described in Brandsma at al. (2014).

3 MATHEMATICAL STRUCTURE OF RHOMOLO-V2

Our aim in this section is to provide a strictly accurate (hence somewhat technical) description of the system exactly as it is introduced in the code for numerical computations. This requires that sets, subsets and indices be rigorously defined as they are in the code, a task to which we first devote our attention.

3.1 DEFINITION OF SETS, SUBSETS AND INDICES

- Territorial units

We identify territorial units by subscripts *r* or *r'*.

AllR defines the set of all territorial units; this set is partitioned into two subsets, the subset of all regions within the EU, denoted *R*, and the single-element subset *RoW*, the rest of the world. We will need a partition of *R* into countries; these national entities will be indexed by *Cnt*.

- Sectors of economic activity

We identify sectors of economic activity by subscript *s* or *s*'. *AllS* defines the set of all sectors of activity. In RHOMOLO-v2, these are:

AllS = { *Agriculture, Manufacturing + Construction, Trade + Transport, Business Services, Non-market services, R&D* }.

Sector markets may be characterised by different types of competitive games; also, they can be described as operating as regional vs. as national markets. We need therefore define partitions of *AllS.*

A first partition of *AllS* distinguishes those sectors that are specific to regions as opposed to countries. In the current version, only R&D is specified as a national activity. Thus, we define the following subsets of *AllS*:

S = { *Agriculture, Manufacturing + Construction, Trade + Transport, Business Services, Non-market services* }.

RnD = { *R&D* }.

A second partition of *AllS* separates sectors operating under perfect competition (subset $AllS^{CP}$: *CP*=competition perfect) from those operating under imperfect competition (subset $AllS^{CI}$: *CI*=competition imperfect). The model code is written in such a way that this partition can be changed anytime with no cost if judged fit; the base version of RHOMOLO defines this partition as follows:

$AllS^{CP}$ = { *Agriculture, Non-market services* }.

$AllS^{CI}$ = { *Manufacturing + Construction, Trade + Transport, Business Services, R&D* }.

We identify sectors that are both regional and perfectly competitive (hence, that belong to the intersection between S and $AllS^{CP}$) as opposed to those that are both regional and imperfectly competitive (hence, that belong to the intersection between S and $AllS^{CI}$) by defining the subsets S^{CP} and S^{CI} *:*

S^{CP} = { *Agriculture, Non-market services* }

S^{CI} = { *Manufacturing + Construction, Trade + Transport, Business Services* }.

- Production factors

We identify production factors by subscript f.

Obviously, production factors differ between each other in a number of ways, depending on the criterion used: it may be types (labour as opposed to capital, labour by skill level etc.), ownership (private vs. public), markets on which they are priced etc. Furthermore, the resulting partitions may overlap with some factors belonging to more than one category. To manage this in the code, it is useful to define the following set and subsets.

AllF defines the set of all factors introduced in the model:

AllF= { *Lab-L, Lab-M, Lab-H, Lab-H-RnD, Lab-H-NonRnD, KapHou, KapGov, KapEur* }

where

Lab-L, Lab-M, Lab-H labels respectively low-, medium- and high-skill labour;

Lab-H-RnD, Lab-H-NonRnD labels high-skill labour specific to R&D vs. non-R&D specific;

KapHou, KapGov labels capital owned by households as opposed to public capital;

KapEur labels capital supplied by an aggregate EU agent (to be defined later).

We next introduce subsets of *AllF.*

AllFEndo refers to all households' factor endowments:

AllFEndo= { *Lab-L, Lab-M, Lab-H, KapHou* }

AllLEndo refers to all households' labour endowments:

AllLEndo= { *Lab-L, Lab-M, Lab-H* }

AllFUsed defines the set of all factors used in production:

AllFUsed= { *Lab-L, Lab-M, Lab-H-RnD, Lab-H-NonRnD, KapGov, KapEur* }.

(Note in particular that firms do not rent capital services directly from households.)

AllLUsed defines the set of all labour types used in production:

AllLUsed= { *Lab-L, Lab-M, Lab-H-RnD, Lab-H-NonRnD* }.

LUsed-H distinguishes between two segmented high skill labour markets (hence with two different market prices), a regional (non-RnD) and a national (RnD):

LUsed-H= { *Lab-H-RnD, Lab-H-NonRnD* }.

LUsed-NonH defines the subset of labour service types used by firms operating regionally (i.e. non-R&D firms):

LUsed-NonH = { *Lab-L, Lab-M, Lab-H-NonRnD* }.

Finally, *AllKUsed* defines the set of all capital types used by firms:

AllKUsed= {*KapGov, KapEur* }.

3.2 HOUSEHOLDS

In each region $r \in R$ there is a single representative household that owns four types of production factors with endowments assumed fixed, and denoted $F_{r,f}^{SupHou}$, with $f \in AllFEndo$, namely high-, medium- and low-skill labour, and private capital. Wages may be fully flexible (hence ensuring labour market clearing) or constrained (hence resulting in endogenous unemployment rates) so that the amount of factors actually rewarded can be written as $\left(1 - UnEmpRte_{r,f}\right)F_{r,f}^{SupHou}$, with associated rental prices $p_{r,f}^{Fac}$, $f \in AllLEndo$.

Furthermore, high-skill labour is endogenously allocated by households to two segmented markets, the national R&D and the regional (equivalently: local) non-R&D markets for high-skill labour. The optimal allocation choice is constrained by a *Constant Elasticity of Transformation* (here after CET) technology that transforms the aggregate amount of $F_{r,Lab-H}^{SupHou}$ into supplies of factors $F_{r,f}^{SupHou}$, $f \in LUsed - H$:

$$\left[1 - UnEmpRte_{r,Lab-H}\right] F_{r,Lab-H}^{SupHou} = \left(\sum_{f \in LUsed-H} \alpha_{r,f}^{FacSupLab-H} \left(F_{r,f}^{supHou}\right)^{\frac{1+\sigma_r^{FacSupLab-H}}{\sigma_r^{FacSupLab-H}}} \right)^{\frac{\sigma_r^{FacSupLab-H}}{1+\sigma_r^{FacSupLab-H}}}$$

where $\alpha_{r,f}^{FacSupLab-H}$ are share parameters and $\sigma_r^{FacSupLab-H}$ is a transformation elasticity.[8] The first order conditions that govern this optimal allocation choice are the following:

$$\left[p_{r,Lab-H}^{Fac}\right]^{1+\sigma_r^{FacSupLab-H}} = \sum_{f \in LUsed-H} \alpha_{r,f}^{FacSupLab-H} \left[p_{r,f}^{Fac}\right]^{1+\sigma_r^{FacSupLab-H}} \qquad (1)$$

[8] The numerical values adopted for elasticities in RHOMOLO are presented in section 4.5.

$$F_{r,f}^{supHou} = \alpha_{r,f}^{FacSupLab-H}\left[\frac{p_{r,f}^{Fac}}{p_{r,Lab-H}^{Fac}}\right]^{\sigma_r^{FacSupLab-H}} \left[1 - UnEmpRte_{r,Lab-H}\right] F_{r,Lab-H}^{supHou}, \quad f \in LUsed - H \qquad (2)$$

with $p_{r,Lab-H}^{Fac}$ denoting the aggregate rental price earned by households for their high-skill labour. Note that this optimal system implies by construction that

$$p_{r,Lab-H}^{Fac} F_{r,Lab-H}^{SupHou} = \sum_{f \in LUsed-H} p_{r,f}^{Fac} F_{r,f}^{SupHou}$$

Physical capital is assumed to be rented by households on a single EU-wide market at a price denoted $p^{EuroKap}$ so that

$$p_{r,KapHou}^{Fac} = p^{EuroKap}. \qquad (3)$$

In order to ease accounting, the household in region $r \in R$ is assumed to earn the profits $Prof_{r,s}$ from all the $N_{r,s}$ imperfectly competitive firms operating in region $r \in R$ sector $s \in AllS$. It also receives transfers from the local (i.e. regional) government, $Transf_r^{Gov \to Hou}$, so that its income Inc_r^{Hou} writes as:

$$\begin{aligned} Inc_r^{Hou} = &\sum_{f \in AllFEndo} p_{r,f}^{Fac} \left(1 - UnEmpRte_{r,f}\right) F_{r,f}^{SupHou} + Transf_r^{Gov \to Hou} \\ &+ \sum_{s \in AllS} N_{r,s} Prof_{r,s}. \end{aligned} \qquad (4)$$

The household pays income taxes, $Tx_r^{Inc^{Hou}}$, to the local government at rate $TxR_r^{Inc^{Hou}}$,

$$Tx_r^{Inc^{Hou}} = TxR_r^{Inc^{Hou}} Inc_r^{Hou}, \qquad (5)$$

it receives/pays transfers to some agents outside the EU (in amount $p_r^{Con^{Hou}} Transf_r^{Hou \to RoW}$ where $p_r^{Con^{Hou}}$ is the aggregate consumption price index) and saves Sav_r^{Hou}, a constant fraction (at rate $SavR_r^{Hou}$) of its disposable income:

$$Sav_r^{Hou} = SavR_r^{Hou}\left(Inc_r^{Hou} - Tx_r^{Inc^{Hou}} - p_r^{Con^{Hou}} Transf_r^{Hou \to RoW}\right). \qquad (6)$$

Aggregate consumption spending in region $r \in R$, Con_r^{Hou}, then writes as:

$$p_r^{Con^{Hou}} Con_r^{Hou} = (1 - SavR_r^{Hou})\left(Inc_r^{Hou} - Tx_r^{Inc^{Hou}} - p_r^{Con^{Hou}} Transf_r^{Hou \to RoW}\right). \qquad (7)$$

The sectoral composition of household consumption is described by *Constant Elasticity of Substitution* (hereafter CES) preferences:

$$Con_r^{Hou} = \left(\sum_{s \in AllS} \left[\alpha_{r,s}^{ConS^{Hou}} \right]^{\frac{1}{\sigma_r^{Con^{Hou}}}} \cdot \left(ConS_{r,s}^{Hou} \right)^{\frac{\sigma_r^{Con^{Hou}}-1}{\sigma_r^{Con^{Hou}}}} \right)^{\frac{\sigma_r^{Con^{Hou}}}{\sigma_r^{Con^{Hou}}-1}}$$

where $ConS_{r,s}^{Hou}$ is the consumption volume of good *s*, $\alpha_{r,s}^{ConS^{Hou}}$ are share parameters, and $\sigma_r^{Con^{Hou}}$ is the elasticity of substitution between these goods. The associated CES ideal price index, $p_r^{Con^{Hou}}$ is defined in terms of the prices $p_{r,s}^{Arm}$ of the different sector-*s* market goods:

$$\left[p_r^{Con^{Hou}} \right]^{1-\sigma_r^{Con^{Hou}}} = \sum_{s \in AllS} \alpha_{r,s}^{ConS^{Hou}} \left[p_{r,s}^{Arm} \right]^{1-\sigma_r^{Con^{Hou}}} \quad (8)$$

and the optimal household consumption demand for market good *s*, $ConS_{r,s}^{Hou}$, writes as:

$$ConS_{r,s}^{Hou} = \alpha_{r,s}^{ConS^{Hou}} \left(\frac{p_r^{Con^{Hou}}}{p_{r,s}^{Arm}} \right)^{\sigma_r^{Con^{Hou}}} Con_r^{Hou}. \quad (9)$$

The household's consumption decision problem is schematised in Figure 1.

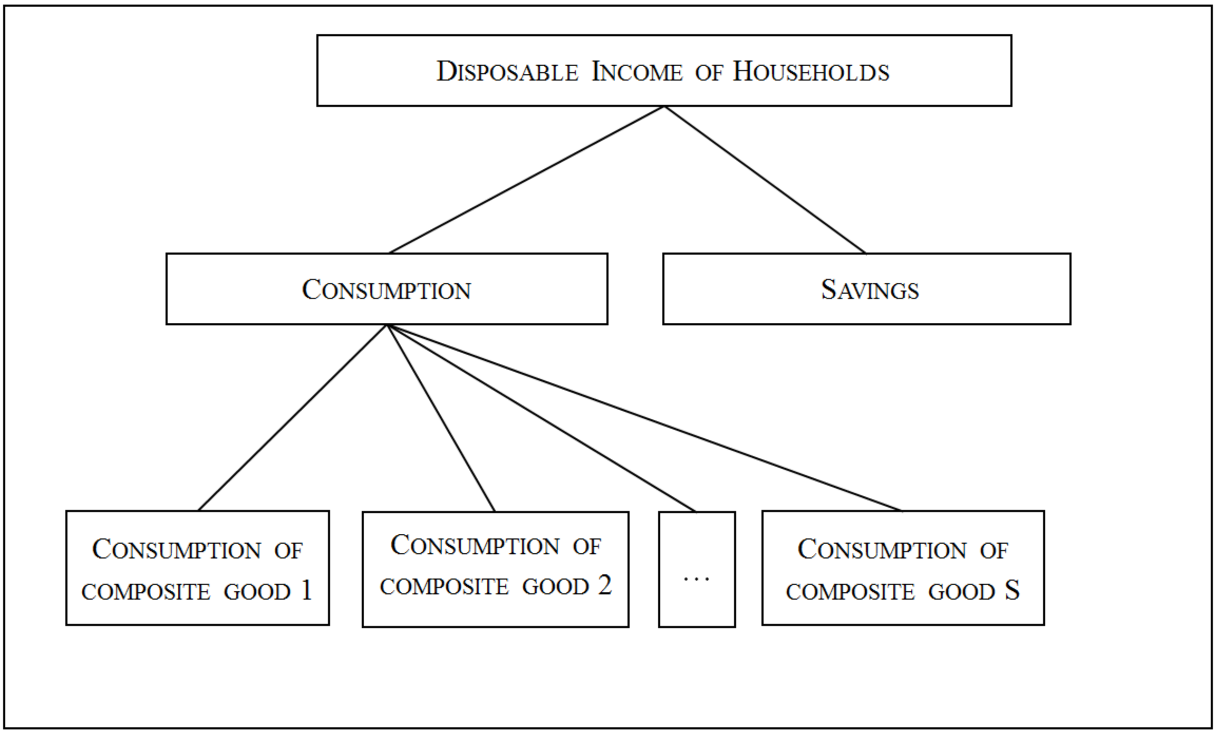

Figure 1: Household preferences in region *r*

3.3 FIRMS

The economy includes sectors that are perfectly competitive (belonging to subset *SCP*) and others that operate under imperfect competition (belonging to subset *SCI*). Both types of firms are price takers on their input markets. In perfectly competitive sectors, firms have constant returns to scale technologies, minimise costs and are constrained to marginal cost pricing. In imperfectly competitive sectors, individual firms optimally determine their variable input demands using similar constant returns to scale technologies (hence minimising their variable unit costs); they however, in addition, face fixed costs modelled in the form of fixed amounts produced that are unfit to be sold and therefore wasted. This introduces increasing returns to scale in production: to survive, these firms have to charge positive mark-ups over marginal costs. These mark-ups are determined optimally conditional on assumptions on the competitive game, as well as on the properties of the demand curve that these firms face.

We start by describing the behaviour of an imperfectly competitive firm of region $r \in R$ sector $s \in SCI$ - hereafter a (r, s)-firm - following Mercenier (1995a, 1995b).

We first express the optimal mark-ups of prices - charged on each individual client market $r' \in AllR$ - over the marginal production cost (to be determined later) as a function of the firm's market power on that individual market, as captured by the Lerner index, $Lerner_{r,s,r'}$:

$$\frac{p_{r,s,r'}^{Exp} - Ma_{r,s}^{Cost}}{p_{r,s,r'}^{Exp}} = Lerner_{r,s,r'} \quad , \quad r' \in AllR \qquad (10)$$

Note that this formulation implies that regional markets are potentially segmented. The Lerner index depends on the type of imperfect competition that is assumed to prevail, as well as on firms' possibly non negligible market shares; we assume the competitive game is Nash either in prices (Bertrand) or in quantities (Cournot). Though all imperfectly competitive markets need not be characterised by the same competitive game (some markets could be of the Bertrand type and others of the Cournot type: the program allows this), the default assumption is Bertrand competition. The (r, s)-firm Lerner index corresponding to each of the two market structures are:

- if Bertrand assumed:

$$Lerner_{r,s,r'} = \frac{1}{\sigma_{r',s}^{Arm} - \left(\sigma_{r',s}^{Arm} - 1\right) MSh_{r,s,r'}} \quad , \quad r' \in AllR \qquad (11)$$

- if Cournot assumed:

$$Lerner_{r,s,r'} = \frac{1}{\sigma_{r',s}^{Arm}} - \left(\frac{1}{\sigma_{r',s}^{Arm}} - 1\right) MSh_{r,s,r'} \quad , \quad r' \in AllR \qquad (12)$$

where $\sigma_{r',s}^{Arm}$ is the price substitution elasticity that governs market r' 's demand system, and $MSh_{r,s,r'}$ denotes the (r,s)-firm's market share on that specific r' market. Firms' optimal mark-ups are therefore endogenous, with market shares (and therefore monopoly power) adjusting with market conditions:

$$MSh_{r,s,r'} = \frac{\left(1 + TxR_{r,s}^{Z}\right) p_{r,s,r'}^{Exp} Exp_{r,s,r'}}{p_{r',s}^{Arm} Arm_{r',s}} \quad , \quad r' \in AllR \tag{13}$$

where $\left(1 + TxR_{r,s}^{Z}\right) p_{r,s,r'}^{Exp} Exp_{r,s,r'}$ is the value of exports of the (r,s)-firm to market r' inclusive of taxes levied at rate $TxR_{r,s}^{Z}$ by the government of region r, and $p_{r',s}^{Arm} Arm_{r',s}$ is the aggregated value of the (r',s) market. The previous equations express for each firm the optimal selling price on all markets (including the local market with $r' = r$), conditional on its marginal production cost, $Ma_{r,s}^{Cost}$. We can then express the firm's average selling price $p_{r,s}^{Z}$ as the sum of the prices charged on each client market weighted by the relative size each market represents for that firm:

$$p_{r,s}^{Z} = \frac{\sum_{r' \in AllR} p_{r,s,r'}^{Exp} Exp_{r,s,r'}}{\sum_{r' \in AllR} Exp_{r,s,r'}} \tag{14}$$

As previously mentioned, the (r,s)-firm's fixed costs of production are measured in terms of foregone output, so that they may be expressed as quantities $Fx_{r,s}^{Cost}$ of produced goods valued at marginal production cost $Ma_{r,s}^{Cost}$, which makes the firm's average production cost $Av_{r,s}^{Cost}$ equal to:

$$Av_{r,s}^{Cost} Z_{r,s} = Ma_{r,s}^{Cost}\left[Z_{r,s} + Fx_{r,s}^{Cost}\right] \tag{15}$$

where $Z_{r,s}$ denotes the total volume of sales (the total production volume being $Z_{r,s} + Fx_{r,s}^{Cost}$). The firm's profits, $Prof_{r,s}$, are computed as the difference between the average selling price and the average production cost, times the firm's sales volume:

$$Prof_{r,s} = \left[p_{r,s}^{Z} - Av_{r,s}^{Cost}\right] Z_{r,s} \tag{16}$$

Observe that computationally, the previous equations are consistent with perfect competition and constant returns to scale technologies provided we impose $Lerner_{r,s,r'} = 0$ and $Fx_{r,s}^{Cost} = 0$ for $s \in SCP$ (hence equations (10) and (14) are actually used in the code for both types of firms). Observe also that the previous variables are determined conditional on knowing the level of the marginal costs, which can be generated for both competitive and imperfectly competitive sectors alike using similar constant returns to scale technological structures, the description of which we now turn to. The firm's production technology is schematised in Figure 2.

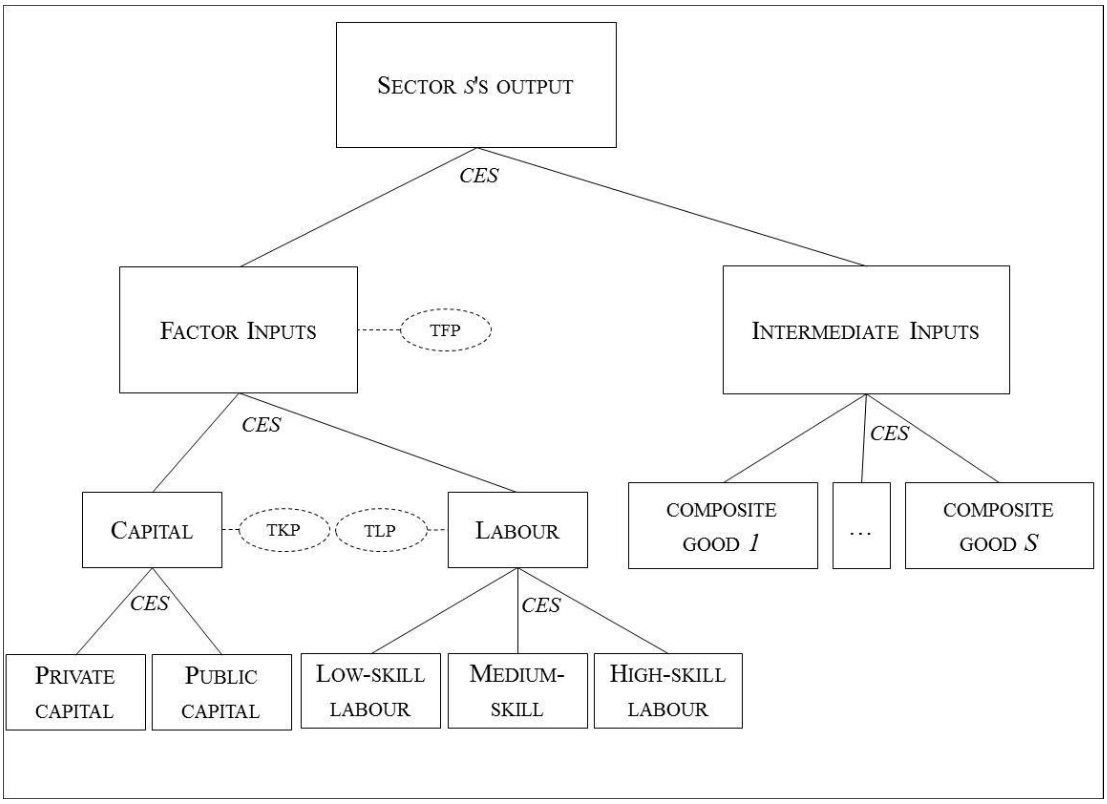

Figure 2: Sector *s*'s nested production function.

All (r,s) producers, $r \in R, s \in S$, minimise their variable unit costs resulting from using a three-level CES production function. The nested structure is depicted in Figure 2.[9] The same structure is adopted for all industries except for the R&D sector, which uses specialised high-skill R&D labour as the only input in the production of innovation (as described in section 3.8).

On the top level of the (r,s)-firm's production function, a CES form constrains the degree of substitutability between intermediate inputs and aggregate value added. The second tier trades-off between different intermediate material inputs on the one hand, and between the use of capital and aggregate labour services on the other. The bottom level of (r,s)-firm's production function defines the substitution possibilities between the different types of labour and between two types of capital, privately owned capital vs. public capital.

We now formalise the optimal input choices of the (r,s)-firm, $r \in R, s \in S$. At the upper level, the firm has to choose the optimal mix between the aggregate intermediate input $X_{r,s}$ and aggregate value added $Q_{r,s}$. Denoting the associated input price indices by $p_{r,s}^{X}$, and $p_{r,s}^{Q}$ respectively, the minimal marginal cost, $Ma_{r,s}^{Cost}$, writes as:

$$\left[Ma_{r,s}^{Cost}\right]^{1-\sigma_{r,s}^{Z}} = \alpha_{r,s}^{X}\left[p_{r,s}^{X}\right]^{1-\sigma_{r,s}^{Z}} + \alpha_{r,s}^{Q}\left[p_{r,s}^{Q}\right]^{1-\sigma_{r,s}^{Z}} \tag{17}$$

[9] In Figure 2, *TFP*, *TKP* and *TLP* denote productivity shift factors that will be introduced soon.

where $\alpha^X_{r,s}$ and $\alpha^Q_{r,s}$ are share parameters, and $\sigma^Z_{r,s}$ is the substitution elasticity between the intermediate input aggregate and value added; the associated optimal demand system is:

$$X_{r,s} = \alpha^X_{r,s}\left[\frac{MA^{Cost}_{r,s}}{p^X_{r,s}}\right]^{\sigma^Z_{r,s}}\left[Z_{r,s} + Fx^{Cost}_{r,s}\right] \tag{18}$$

$$Q_{r,s} = \alpha^Q_{r,s}\left[\frac{MA^{Cost}_{r,s}}{p^Q_{r,s}}\right]^{\sigma^Z_{r,s}}\left[Z_{r,s} + Fx^{Cost}_{r,s}\right] \tag{19}$$

In a similar way, we can solve the first order condition systems for the second level CES input aggregators $X_{r,s}$ and $Q_{r,s}$ and obtain the optimal composition of the intermediate input mix $X_{r,s}$ as:

$$\left[p^X_{r,s}\right]^{1-\sigma^X_{r,s}} = \sum_{s\prime\in AllS} \alpha^{XS}_{r,s\prime,s}\left[p^{Arm}_{r,s\prime}\right]^{1-\sigma^X_{r,s}} \tag{20}$$

$$XS_{r,s\prime,s} = \alpha^{XS}_{r,s\prime,s}\left(\frac{p^X_{r,s}}{p^{Arm}_{r,s\prime}}\right)^{\sigma^X_{r,s}} X_{r,s} \qquad s' \in AllS \tag{21}$$

where $\alpha^{XS}_{r,s\prime,s}$ are the share parameters associated with the intermediate demand for sector s' goods bought at market price $P^{Arm}_{r,s\prime}$, and $\sigma^X_{r,s}$ is the substitution elasticity between material inputs. The optimal composition of the value added mix $Q_{r,s}$ is determined by a similar system of equations:

$$TFP_{r,s} = TFP0_{r,s}\left[\frac{KnowK_{Cnt}}{KnowK0_{Cnt}}\right]^{KnowK^{Ext}_{r,s}}, \quad r \in Cnt \tag{22}$$

$$\left[p^Q_{r,s}\right]^{1-\sigma^Q_{r,s}} = TFP_{r,s}{}^{\sigma^Q_{r,s}-1}\left[\alpha^{KapDem}_{r,s}\left[p^{Kap}_{r,s}\right]^{1-\sigma^Q_{r,s}} + \alpha^{LabDem}_{r,s}\left[p^{Lab}_{r,s}\right]^{1-\sigma^Q_{r,s}}\right] \tag{23}$$

$$Kap^{Dem}_{r,s} = TFP_{r,s}{}^{\sigma^Q_{r,s}-1}\alpha^{KapDem}_{r,s}\left[\frac{p^Q_{r,s}}{p^{Kap}_{r,s}}\right]^{\sigma^Q_{r,s}} Q_{r,s} \tag{24}$$

$$Lab^{Dem}_{r,s} = TFP_{r,s}{}^{\sigma^Q_{r,s}-1}\alpha^{LabDem}_{r,s}\left[\frac{p^Q_{r,s}}{p^{Lab}_{r,s}}\right]^{\sigma^Q_{r,s}} Q_{r,s} \tag{25}$$

where, as usual, the α's and σ's are share parameters and substitution elasticities respectively.[10] $TFP_{r,s}$ is a total factor productivity shift factor that endogenously evolves with the accumulation of

[10] Notice that, in the special case of $\sigma^Q_{r,s} = 1$, the CES degenerates into a Cobb-Douglas and equations (23), (24) and (25) have to be computed as follows:

$$p^Q_{r,s} = TFP_{r,s}{}^{-1}\left[\left[p^{Kap}_{r,s}\right]^{\alpha^{KapDem}_{r,s}}\left[p^{Lab}_{r,s}\right]^{1-\alpha^{KapDem}_{r,s}}\right] \tag{23a}$$

$$Kap^{Dem}_{r,s} = \alpha^{KapDem}_{r,s}\left[\frac{p^Q_{r,s}}{p^{Kap}_{r,s}}\right] Q_{r,s} \tag{24a}$$

$$Lab^{Dem}_{r,s} = \alpha^{LabDem}_{r,s}\left[\frac{p^Q_{r,s}}{p^{Lab}_{r,s}}\right] Q_{r,s} \tag{25a}$$

a country specific knowledge capital stock $KnowK_{Cnt}$ ($KnowK^{Ext}_{r,s}$ is a knowledge externality parameter the value of which commands the amplitude of the knowledge spill-over to sector s in region r; $TFP0_{r,s}$ and $KnowK0_{Cnt}$ are respectively the base year values of $TFP_{r,s}$ and $KnowK_{Cnt}$); $p^{Kap}_{r,s}$ and $p^{Lab}_{r,s}$ are respectively the price of the capital and of the labour aggregate input mixes $Kap^{Dem}_{r,s}$, $Lab^{Dem}_{r,s}$, prices that are determined by the third-level technology nest.

The third level CES input aggregators condition the optimal compositions of $Kap^{Dem}_{r,s}$ and $Lab^{Dem}_{r,s}$. $Kap^{Dem}_{r,s}$ combines private and public capital inputs $F^{Dem}_{r,s,f}$, $f \in AllKUsed$. The optimal demand system that defines $Kap^{Dem}_{r,s}$ is:

$$\left[p^{Kap}_{r,s}\right]^{1-\sigma^{Kap}_{r,s}} = TKP_{r,s}{}^{\sigma^{Kap}_{r,s}-1} \sum_{f \in AllKUsed} \alpha^{FDem}_{r,s,f}\left[\left(1+TxR^{FDem}_{r,s,f}\right)p^{Fac}_{r,f}\right]^{1-\sigma^{Kap}_{r,s}} \quad (26)$$

$$F^{Dem}_{r,s,f} = TKP_{r,s}{}^{\sigma^{Kap}_{r,s}-1}\alpha^{FDem}_{r,s,f}\left[\frac{p^{Kap}_{r,s}}{\left(1+TxR^{FDem}_{r,s,f}\right)p^{Fac}_{r,f}}\right]^{\sigma^{Kap}_{r,s}} Kap^{Dem}_{r,s} \quad , \ f \in AllKUsed \quad (27)$$

where $TKP_{r,s}$ is an exogenous productivity shift factor, $p^{Fac}_{r,f}$ is the market rental price for the *f*-type capital factor, and $TxR^{FDem}_{r,s,f}$ is the (possibly negative) tax rate on the (r, s)-firm's use of factor *f;* the αs and σs are share parameters and substitution elasticities respectively. The $Lab^{Dem}_{r,s}$ combine the different types of labour skill inputs, high, medium, low: $f \in LUsed - NonH$. The optimal demand system associated with $Lab^{Dem}_{r,s}$ is:

$$\left[p^{Lab}_{r,s}\right]^{1-\sigma^{Lab}_{r,s}} = TLP_{r,s}{}^{\sigma^{Lab}_{r,s}-1} \sum_{f \in LUsed-NonH} \alpha^{FDem}_{r,s,f}\left[\left(1+TxR^{FDem}_{r,s,f}\right)p^{Fac}_{r,f}\right]^{1-\sigma^{Lab}_{r,s}} \quad (28)$$

$$F^{Dem}_{r,s,f} = TLP_{r,s}{}^{\sigma^{Lab}_{r,s}-1}\alpha^{FDem}_{r,s,f}\left[\frac{p^{Lab}_{r,s}}{\left(1+TxR^{FDem}_{r,s,f}\right)p^{Fac}_{r,f}}\right]^{\sigma^{Lab}_{r,s}} Lab^{Dem}_{r,s} \quad , \quad f \in LUsed - NonH \quad (29)$$

where $TLP_{r,s}$ is an exogenous productivity shift factor, $P^{Fac}_{r,f}$ is the market rental price for the *f*-type labour factor, and $TxR^{FDem}_{r,s,f}$ is the (possibly negative) tax rate on the use of that factor. (Note that some factors will be excluded if the associated share parameter $\alpha^{FDem}_{r,s,l}$ is equal to zero; for this reason, in the computations, we can here use indifferently the subsets *AllLUsed* and *LUsed-NonH*.)

We complete the description of the producer's behaviour by collecting in the following equations the taxes paid to the local government by the (r, s)-firm:

$$Tx^{FDem}_{r,s,f} = TxR^{FDem}_{r,s,f}\, p^{Fac}_{r,f}\, F^{Dem}_{r,s,f} \quad , \ f = AllFUsed \quad (30)$$

$$Tx^{Z}_{r,s} = TxR^{Z}_{r,s}\, p^{Z}_{r,s}\, Z_{r,s} \quad , \ s \in S \quad (31)$$

3.4 INVESTMENT DEMAND FOR LOCAL GOODS

In each region, there is an aggregate level of real investment demand denoted Inv_r - the level of which will be determined later - assumed to be a CES mix of the region's market goods (with share parameters $\alpha_{r,s}^{Inv}$ and substitution elasticity σ_r^{Inv}). The optimal composition of Inv_r is:

$$[p_r^{Inv}]^{1-\sigma^{Inv}} = \sum_{s\in AllS} \alpha_{r,s}^{Inv}\left[p_{r,s}^{Arm}\right]^{1-\sigma^{Inv}} \tag{32}$$

$$InvS_{r,s} = \alpha_{r,s}^{Inv}\left[\frac{p_r^{Inv}}{p_{r,s}^{Arm}}\right]^{\sigma^{Inv}} Inv_r \quad , \quad s \in\ AllS \tag{33}$$

where $InvS_{r,s}$ is the investment demand for sector s market goods bought at prices $p_{r,s}^{Arm}$, and p_r^{Inv} is the marginal cost of the investment aggregate Inv_r.

3.5 THE GOVERNMENT

The regional government earns revenues from renting public capital, $F_{r,KapGov}^{SupGov}$, to firms at price $p_{r,KapGov}^{Fac}$; it collects taxes on the local household income, $Tx_r^{Inc^{Hou}}$, on local firms' productions, $Tx_{r,s}^{Z}$, and on factor inputs, $Tx_{r,s,f}^{F^{Dem}}$; given that all taxes from imperfectly competitive firms are measured at the firm level, these variables have to be multiplied by the number of firms $N_{r,s}\ \ , s \in\ SCI$. Collecting these terms, we define the regional government's total revenue as:

$$Inc_r^{Gov} = Tx_r^{Inc^{Hou}} + \sum_{s\in AllS} N_{r,s}Tx_{r,s}^{Z} + \sum_{s\in AllS, f\in AllFUsed} N_{r,s}Tx_{r,f,s}^{F^{Dem}} + p_{r,KapGov}^{Fac}F_{r,KapGov}^{SupGov} \tag{34}$$

where here (and hereafter) $N_{r,s}$ is constant and set to unity in perfectly competitive industries. Real public consumption, Con_r^{Gov}, is endogenous and determined by the public sector's period budget constraint; it is composed of local final goods, combined assuming a CES aggregator (with substitution elasticity σ_r^{Gov} and share parameters $\alpha_{r,s}^{Con^{Gov}}$). The optimal public demand system for the market goods writes as:

$$\left[p_r^{Con^{Gov}}\right]^{1-\sigma_r^{Con^{Gov}}} = \sum_{s\in AllS} \alpha_{r,s}^{Con^{Gov}}\left[p_{r,s}^{Arm}\right]^{1-\sigma_r^{Con^{Gov}}} \tag{35}$$

$$ConS_{r,s}^{Gov} = \alpha_{r,s}^{Con^{Gov}}\left[\frac{p_r^{Con^{Gov}}}{p_{r,s}^{Arm}}\right]^{\sigma_r^{Con^{Gov}}} Con_r^{Gov} \quad , \quad s \in\ AllS \tag{36}$$

where $p_r^{Con^{Gov}}$ is the price index of aggregate public consumption and $ConS_{r,s}^{Gov}$ denotes the demand for local market good s with associated price, $p_{r,s}^{Arm}$.

Governments also pay transfers to households, which are assumed to remain constant in real terms (at their base year value $Transf0_r^{Gov\to Hou}$), though indexed by $p_r^{Con^{Gov}}$:

$$Transf_r^{Gov\to Hou} = p_r^{Con^{Gov}} Transf0_r^{Gov\to Hou} \qquad (37)$$

Government savings Sav_r^{Gov} are exogenous; the public sector's flow budget constraint therefore determines the level of public consumption expenditures; it writes as:

$$Sav_r^{Gov} = Inc_r^{Gov} - p_r^{Con^{Gov}} Con_r^{Gov} - Transf_r^{Gov\to Hou} \qquad (38)$$

Observe that there is no endogenously determined investment in public capital: we assume a zero depreciation rate and no investment on public capital, so that $F_{r,KapGov}^{SupGov}$ is held fixed.

3.6 PRICE, LEVEL AND COMPOSITION OF THE DEMAND FOR MARKET GOODS

In each region the level of aggregate demand, $Arm_{r,s}$, for market goods *s* is determined by summing intermediate demands by all firms, and all components of final demands:

$$Arm_{r,s} = \sum_{s'\in AllS} N_{r,s'}\ XS_{r,s,s'} + ConS_{r,s}^{Hou} + ConS_{r,s}^{Gov} + InvS_{r,s} + StVar_{r,s} \quad , \quad s \in AllS \qquad (39)$$

where $StVar_{r,s}$ denotes stock variations, which are kept exogenously fixed at their base year value.[11]

In perfectly competitive sectors, this good is a CES aggregate of domestically produced and imported goods (from each other region, plus the RoW). This is one particular formulation of the usual Armington assumption (hence the acronym used). In imperfectly competitive sectors, we use the Dixit-Stiglitz specification capturing product differentiation at the individual firm level. Though conceptually quite different indeed, from a computational perspective we can formulate the two assumptions identically conditional on fixing to unity the number of firms in the perfectly competitive sectors.

Let $Exp_{r',s,r}$ denote the demand by region *r* for sector *s* goods supplied by an individual firm producing in regions *r'*; the mill price of the good is $p_{r',s,r}^{Exp}$ to which one has to add taxes (at rate $TxR_{r',s}^{Z}$ paid to the Government of origin) and iceberg transport costs (at net rate $TrCost_{r',s,r}$). CES cost minimisation (with substitution elasticity $\sigma_{r,s}^{Arm}$ and share parameters $\alpha_{r',s,r}^{Exp}$) then yields the following demand system from first order conditions:

[11] Stock variations are usually included in gross investment. However, in some regions negative values for the former variable exceed in absolute terms the values of the later. For this reason, we treat the two variables separately.

$$[p_{r,s}^{Arm}]^{1-\sigma_s^{Arm}} = \sum_{r' \in AllR} N_{r',s} \alpha_{r',s,r}^{Exp} \left[(1 + TrCost_{r',s,r})(1 + TxR_{r',s}^{Z}) p_{r',s,r}^{Exp}\right]^{1-\sigma_s^{Arm}}, \quad r \in AllR, s \in S \quad (40)$$

$$\frac{Exp_{r',s,r}}{1 + TrCost_{r',s,r}} = \alpha_{r',s,r}^{Exp} \left[\frac{p_{r,s}^{Arm}}{(1 + TrCost_{r',s,r})(1 + TxR_{r',s}^{Z}) p_{r',s,r}^{Exp}}\right]^{\sigma^{Arm}} Arm_{r,s} \quad , \quad r, r' \in AllR, \quad s \in AllS \quad (41)$$

Observe that the system of equations generates a complete endogenous non-zero diagonal matrix of bilateral trade flows for each sector.[12] The only activity that makes exception is the R&D sector where trade takes place only within national boundaries (as will be explained later) without price discrimination so that

$$p_{r,RnD}^{Arm} = p_{Cnt,RnD}^{Z}. \quad (42)$$

3.7 THE EUROPEAN CAPITAL MARKET

In order to allow for capital to move internationally, we assume a fictitious European agent whose role is to collect all capital supplied by households throughout Europe, and to allocate its flow services between regional markets taking into account differences in rental prices (we shall assume for this a CET-constrained optimal allocation process). Regional households are then rewarded proportionally to their contributions to the aggregate stock at the European average rental price of capital. For this summing of capital across regions to be meaningful, it is necessary that these stocks be identically valued. For this purpose, we assume that the aggregate European agent collects all the savings supplied by households within the EU; it then uses a single investment technology combining market goods from each region to convert this aggregate saving into capital goods (we shall assume for this a multilevel CES-constrained optimal mixing process). The adopted set-up has the obvious advantage of simplifying the keeping track of capital ownerships and incomes. We next formalise these ideas.

Collecting all savings within region *r*, we get

$$Sav_r = Sav_r^{Hou} + Sav_r^{Gov} + Sav_r^{EU \to r} + Sav_r^{ROW \to r} \quad , r \in R \quad (43)$$

where $Sav_r^{EU \to r}$ and $Sav_r^{ROW \to r}$ denote the region's exogenously fixed trade balances with respect to other EU regions (the sum over all regions of $Sav_r^{EU \to r}$ being equal to zero), and the rest of the world (RoW), respectively.

Summing over regions, we get the aggregate EU resource flow available for investment:

$$EuroInc^{Inv} = \sum_{r \in R} Sav_r \quad (44)$$

[12] The equation also applies for the RoW, with diagonal share parameters set to zero: $\alpha_{RoW,s,RoW}^{Exp} = 0$.

with the flow addition $EuroInv$ to the EU capital stock determined by

$$p^{EuroInv} EuroInv = EuroInc^{Inv}. \tag{45}$$

where $p^{EuroInv}$ is the unit cost of the aggregate EU investment good. This aggregate good results from combining goods from different regions using a two level CES structure. At the upper level, regional investment aggregates, Inv_r, are CES-combined (with substitution elasticity $\sigma^{EuroInv}$ and share parameters $\alpha_r^{EuroInv}$) using the following system of first order conditions:

$$[p^{EuroInv}]^{1-\sigma^{EuroInv}} = \sum_{r \in R} \alpha_r^{EuroInv} [p_r^{Inv}]^{1-\sigma^{EuroInv}} \tag{46}$$

$$Inv_r = \alpha_r^{EuroInv} \left[\frac{p^{EuroInv}}{p_r^{Inv}}\right]^{\sigma^{EuroInv}} EuroInv \qquad , r \in R \tag{47}$$

to produce $EuroInv$. At the lower level, market goods from each region are combined to generate the optimal investment mix Inv_r: this CES aggregate and the associated cost structure have been previously described, see equations (32) and (33).[13]

Turning to fixed capital services, we can sum the supplies $F_{r,KapHou}^{SupHou}$ from households across regions to generate the total supply within the EU:

$$EuroKap = \sum_{r \in R} F_{r,KapHou}^{SupHou} \tag{48}$$

$EuroKap$ is then split optimally between regional factor markets using a CET allocation technology (with elasticity of transformation σ^{EurKap} and share parameters $\alpha_r^{SupKapEur}$) described by the following first order condition system:

$$[p^{EuroKap}]^{1+\sigma^{EuroKap}} = \sum_{r \in R} \alpha_r^{SupKapEur} [P_{r,KapEur}^{Fac}]^{1+\sigma^{EurKap}} \tag{49}$$

$$F_{r,KapEur}^{SupHou} = \alpha_r^{SupKapEur} \left[\frac{p_{r,KapEur}^{Fac}}{p^{EuroKap}}\right]^{\sigma^{EuroKap}} EuroKap \quad , \qquad r \in R \tag{50}$$

[13] Equation (44) implies that investments are savings driven. This is the default option in RHOMOLO. However, the model can also be run making the decision of investments independent from the decisions of savings. In this particular case, the optimal of investments is driven by the gap between the desired level of capital and the actual level of capital, adjusted by depreciation in line with Jorgenson's (1963) and Uzawa's (1969) theory of investment behaviour. Implementing this, however, requires relaxing the assumption of a fixed trade balance with respect to the RoW: the variable $Sav_r^{ROW \to r}$ becomes endogenous with regions becoming unconstrained in their ability to borrow or lend to the RoW at world constant interest rate. Of course, there may be cases in which this assumption may raise some concern, as for example in the case of not benefitting of unconstrained access to international financial markets for structural or conjunctural reasons.

Observe that by this formulation we make physical capital imperfectly mobile between regions (with parameter σ^{EurKap} commanding how easy/costly this mobility is) yet allowing financial capital to move freely within Europe.

3.8 A NATIONAL SECTOR OF ACTIVITY: R&D AND INNOVATION

Given the specific spatial dimension of R&D activities, which are often produced by firms clustered in few regions of a country while knowledge is used by firms located anywhere, RHOMOLO models 27 national R&D sectors, which produce innovation services using a specific high-skill labour factor rented from households in all regions of the country. Since R&D services are used as intermediate inputs by all other sectors of activity, their demands in each region of the country depend on the relative price of R&D with respect to other intermediate inputs and production factors.

With the R&D market structure assumed imperfectly competitive (more specifically Bertrand-Nash), the price of the R&D services $p^{Z}_{Cnt,RnD}$ is set by national firms (as opposed to regional firms: note the country index Cnt) above marginal production costs $Ma^{Cost}_{Cnt,RnD}$, the mark-up rate reflecting the curvature characteristics of demand functions:[14]

$$p^{Z}_{Cnt,RnD} = Ma^{Cost}_{Cnt,RnD}\left[\frac{\sigma^{Arm}_{Cnt,RnD}}{\sigma^{Arm}_{Cnt,RnD} - 1}\right] \tag{51}$$

In equilibrium, R&D firms satisfy the national demand consistent with the price they charge:

$$Z_{Cnt,RnD} = \sum_{r \in Cnt} Arm_{r,RnD} \tag{52}$$

As in other sectors, the fixed costs are modelled in the form of forgone output therefore valued at marginal production costs; the technology is assumed to be Ricardian in the specific R&D high-skill labour. It follows that

$$Ma^{Cost}_{Cnt,RnD}\left[Z_{Cnt,RnD} + Fx^{Cost}_{Cnt,Rnd}\right] = \sum_{r \in Cnt} p^{Fac}_{r,Lab\_H\_RnD} F^{Dem}_{r,Lab\_H\_RnD} \tag{53}$$

where the LHS of this equation is the value of total production, and the RHS the total rewards to factor inputs. With the Ricardian technology assumption, the marginal production cost is proportional to the price of the factor used:

$$p^{Fac}_{r,Lab-H-RnD} = TFP_{Cnt,RnD} Ma^{Cost}_{Cnt,RnD} \qquad , \ r \in Cnt \tag{54}$$

where $TFP_{Cnt,RnD}$ is an exogenous productivity shift parameter. Finally, potential non-zero profits in the R&D sector,

[14] In the program, this sector (as all the other sectors) may be assumed to operate perfectly competitively, in which case the mark-up rate and fixed costs are set to zero.

$$Prof_{Cnt,RnD} = p^{Z}_{Cnt,RnD} Z_{Cnt,RnD} - Ma^{Cost}_{Cnt,RnD} \left[Z_{Cnt,RnD} + Fx^{Cost}_{Cnt,Rnd} \right] \tag{55}$$

are redistributed to regional households within the country in proportion to their supply of the specific production factor of sector s:

$$Prof_{r,RnD} = Prof_{Cnt,RnD} \frac{F^{dem}_{r,Lab-H-RnD}}{\sum_{r \in Cnt} F^{dem}_{r,Lab-H-RnD}} \tag{56}$$

The number of R&D varieties available in each region is the same for all regions within the same country, so that:

$$N_{r,RnD} = N_{Cnt,RnD} \qquad , \ \ r \in Cnt \tag{57}$$

Here again, the number of national R&D firms can be endogenised by forcing $Prof_{Cnt,RnD}$ to zero, though this is not currently used because it hugely increases the computational costs.

Finally, in the current version of the model, the national stock of knowledge is assumed to fully depreciate after one period and can thus be written as:

$$KnowK_{Cnt} = N_{Cnt,RnD} Z_{Cnt,RnD} \tag{58}$$

3.9 EQUILIBRIUM CONDITIONS

- Factor markets

On production factor markets, prices are flexible and determined by supply and demand equalisation, or are assumed sticky. We introduce the possibility for some (possibly all) wages to be determined by a wage curve: the endogenous wage is then set above its market clearing level, hence inducing non-zero unemployment. We can formalise this by the following sets of equations:

$$\left[1 - UnEmpRte_{f}\right] F^{SupHou}_{r,f} + F^{SupGov}_{r,f} = \sum_{s \in AllS} N_{r,s} F^{Dem}_{r,s,f} \ , \qquad r \in R \, , \quad f \in AllFUsed \tag{59}$$

$$\frac{p^{Fac}_{r,f}}{p^{Con^{Hou}}_{r}} = - \, \varepsilon^{wagecurve} \ \frac{UnEmpRte_{r,f}}{UnEmpRte0_{r,f}} \qquad , \qquad r \in R \, , \quad f \in AllLEndo \tag{60}$$

where $\varepsilon^{wagecurve}_{r}$ is a (positive) elasticity parameter. In markets where factor prices are flexible, the first of these two equations applies with $UnEmpRte_{r,f}$ exogenously set to zero (or possibly to some non-zero base year value). Observe that these equations are defined for all factors used by firms. Such a compact notation of course builds on the fact that some elements of $F^{SupHou}_{r,f}$ and $F^{SupGov}_{r,f}$ are equal to zero by the definition of f; for instance, $F^{SupHou}_{r,f} = 0$ if $f = KapGov$. The second equation is the wage curve; for those markets for which this equation is active, the first equation solves for the equilibrium unemployment rate.

- Goods markets

In non-R&D markets ($s \in S$), the supply of goods equals exports to all (including domestic) markets:

$$Z_{r,s} = \sum_{r' \in AllR} Exp_{r,s,r'} \quad , \quad r \in R \, , \quad s \in S \tag{61}$$

- Free entry conditions for firms in *SCI* sectors

Though computationally challenging (and therefore not used in the default simulation options) the number of firms may be endogenised by incorporation of Chamberlain's famous free/costless entry/exit condition resulting in zero supernormal profits for firms in *SCI* sectors, so that average costs, $Av_{r,s}^{Cost}$, are equal to firms' mill prices, $p_{r,s}^{Z}$:

$$Av_{r,s}^{Cost} = p_{r,s}^{Z} \quad , \quad s \in SCI \tag{62}$$

3.10 THE REST OF THE WORLD

The rest of the world is exogenous except for trade: see equations (40) and (41). We choose the rest of the world prices as *numéraire*, and normalise these to unity:

$$p_{RoW,s,r}^{Exp} = 1 \qquad , \quad r \in AllR$$

Given that in each region within the EU, each agent satisfies its budget constraint, and that all market equilibrium conditions are imposed, we know by Walras' law that the *RoW* budget constraint is redundant since it should automatically be satisfied. We nevertheless check that it is indeed satisfied:

$$\begin{aligned} &\sum_{r \in R} \left(p_{\mathrm{r}}^{Con^{Hou}} Transf_{r}^{Hou \to RoW} + \sum_{s \in AllS} p_{RoW,s,r}^{Exp} Exp_{RoW,s,r} \right) = \\ &= \sum_{r \in R} \left(\sum_{s \in AllS} \left(\left(1 + TxR_{\mathrm{r,s}}^{Z}\right) p_{r,s,RoW}^{Exp} N_{r,s} Exp_{r,s,RoW} \right) + Sav_{r}^{RoW \to R} \right) \end{aligned} \tag{63}$$

where $Sav_{r}^{RoW \to R}$ is exogenously fixed. In order to reduce computation costs, we check that this equation is satisfied *ex post*.

The time period *t* general equilibrium is determined by solving the system of equations (1) to (62).

3.11 Dynamics

3.11.1 The implicit modelling of financial markets

In order to lighten notation, we drop the region r subscript in the exposition of this section when no confusion can arise.

- The local government's supply of bonds

The supply of government bonds is determined by the dynamic budget constraint of the local public sector, which we write as follows:

$$p_t^{Con^{Gov}} B_{t+1}^{Gov} + Inc_t^{Gov} = \left(1 + rint_{t-1}^{Gov}\right) p_{t-1}^{Con^{Gov}} B_t^{Gov} + p_t^{Con^{Gov}} Con_t^{Gov} + Transf_t^{Gov \to hou}$$

where B_{t+1}^{Gov} is the outstanding real stock of bonds (assumed one period lived) held by households (all assumed local) during period $t+1$, that has been issued by the local authorities (at the end of period t) to cover their period t deficit. The LHS of the equation accounts for available resources whereas the RHS accounts for expenses. These expenses include, in addition to public consumption and transfers, interest payments (at rate $rint_{t-1}^{Gov}$) on, and clearing of, its previous period's liabilities.[15]

Different assumptions on the government's behaviour are of course possible, and to each will correspond a different time path for the supply of public bonds, determined by the previous equation. Our main interest is not on public debt management issues in RHOMOLO, so we make the rather neutral assumption that each local government's borrowing needs (expressed in real amount of public consumption goods) remain constant through time, that is, we impose that $p_t^{Con^{Gov}} B_{t+1}^{Gov} = p_{t-1}^{Con^{Gov}} B_t^{Gov}$.

There are no forward looking expectations in the model, and therefore no room for efficient portfolio management that would link together returns on various assets. We therefore make the simplifying assumption that the nominal interest rate on public bonds remains constant, $rint_{t-1}^{Gov} = rint^{Gov}$, and that at this rate demand from local households always meets the supplied stock. Introducing these assumptions in the previous and rearranging, we get:

$$Inc_t^{Gov} - p_t^{Con^{Gov}} Con_t^{Gov} - Transf_t^{Gov \to hou} = rint^{Gov}\, p_{t-1}^{Con^{Gov}} B_t^{Gov}$$

The LHS corresponds to the exogenous variable Sav_t^{Gov} in the model (see (38)) so that:

$$Sav_t^{Gov} = rint^{Gov}\, p_{t-1}^{Con^{Gov}} B_t^{Gov}$$

We further constrain Sav_t^{Gov} to remain constant: $Sav_t^{Gov} = Sav^{Gov}$. Hence, conditional on choosing a reasonable value for the interest rate, we could calibrate for the base year stock of bonds, and

[15] The interest rate $rint_{t-1}^{Gov}$ is indexed $t-1$ to stress that it has been fixed at the time the bonds were issued, and therefore is known with certainty since that date.

compute the implied time path of B_t^{Gov}. However, this is not very useful, and as we shall show, it turns out to be unnecessary.

- The RoW and EU supply of assets

Households also own a portfolio of foreign assets, which we also assume are one-period-lived bonds. The supply of RoW bonds in region r, $B_{t+1,r}^{RoW}$, is determined by the following dynamic equation:

$$p_t^{RoW} B_{t+1,r}^{RoW} + \sum_{s \in AllS} p_{t,RoW,s}^{Exp} Exp_{t,RoW,s,r} + p_{t,r}^{Con^{Hou}} Transf_{t,r}^{Hou \to RoW} = (1 + rint_{t-1}^{RoW}) p_{t-1}^{RoW} B_{t,r}^{RoW} + \sum_{s \in AllS} \left((1 + TxR_{r,s}^Z) p_{t,r,s,RoW}^{Exp} N_{t,r,s} Exp_{t,r,s,RoW} \right)$$

where again the LHS expresses the resources and the RHS the uses. We assume that the value of asset claims on the RoW is constant, and consistent with a fixed interest rate $rint_{t-1}^{RoW} = rint^{RoW}$. Introducing these assumptions into the previous equation and rearranging yields:

$$\sum_{s \in AllS} p_{t,RoW,s}^{Exp} Exp_{t,RoW,s,r} + p_{t,r}^{Con^{Hou}} Transf_{t,r}^{Hou \to RoW} = rint^{RoW} p_{t-1}^{RoW} B_{t,r}^{RoW} + \sum_{s \in AllS} \left((1 + TxR_{r,s}^Z) p_{t,r,s,RoW}^{Exp} N_{t,r,s} Exp_{t,r,s,RoW} \right)$$

This equation is identical to the r component of (63) with

$$Sav_t^{RoW \to R} = rint^{RoW} B_t^{RoW}$$

$Sav_t^{RoW \to R}$ was assumed exogenous; we further impose that it remains constant over time: $Sav_t^{RoW \to R} = Sav^{RoW \to R}$. Hence, conditional on choosing a reasonable constant value for $rint^{RoW}$ (presumably identical to $rint^{Gov}$, possibly adjusted for a region-specific risk-premium), we could determine the stock of RoW bonds held by local households (though this turns out not to be useful nor necessary as will soon be clear).

We can proceed in a similar way for the other EU agents' issued bonds to derive the following equation:

$$Sav_t^{EU \to R} = rint_t^{EU} . B_t^{EU}$$

where $rint_t^{EU}$ is the interest paid on EU bonds. $Sav_t^{EU \to R}$ was assumed exogenously fixed: see (43); we now impose that it remains constant, as well as $rint_t^{EU}$:

$$Sav_t^{EU \to R} = Sav^{EU \to R}$$
$$rint_t^{EU} = rint^{EU}$$

- Wealth accumulation by households

The demand for assets results from the willingness of households to accumulate wealth. We write the regional household's dynamic budget constraint as follows:

$$
\begin{aligned}
W_{t+1} + p_t^{Con^{Hou}} Con_t^{Hou} + Tx_t^{Inc^{hou}} + Transf_t^{Hou\rightarrow RoW} \\
= (1 + rret_{t-1})W_t + \sum_{f\in AllLEndo} p_{t,f}^{Fac}\left(1 - UnEmpRte_f\right)F_{t,f}^{supHou} \\
+ Transf_t^{Gov\rightarrow Hou} + \sum_s N_{t,s} Prof_{t,s}
\end{aligned}
$$

where W_{t+1} is financial wealth owned by the private sector at the beginning of period $t+1$, expressed at current prices, and $rret_{t-1}$ is the average net rate of return of the portfolio. At the LHS are expenditures; the RHS groups resources with $rret_{t-1}W_t$ denoting the flow income during period t from holding assets. Wealth is composed of (claims on) physical capital and bonds held on the local government, on the RoW and on other EU agents. In order to simplify notations, we temporarily drop in the following developments the last two claims. Hence,

$$
W_{t+1} = p_t^{EuroInv} K_{t+1} + p_t^{Con^{Gov}} B_{t+1}^{Gov}
$$

where $p_t^{EuroInv}$ is the price of new capital: see (46). The household's dynamic budget constraint can then be rewritten as:

$$
\begin{aligned}
p_t^{EuroInv} K_{t+1} + p_t^{Gov} B_{t+1}^{Gov} + p_t^{Con^{Hou}} Con_t^{hou} + Tx_t^{Inc^{Hou}} + Transf_t^{Hou\rightarrow RoW} \\
= p_{KapHou}^{Fac}\frac{K_t}{\kappa} + (1-\delta)p_{t-1}^{EuroInv}K_t + \left(1 + rint_{t-1}^{Gov}\right)p_{t-1}^{Gov}B_t^{Gov} \\
+ \sum_{f\in AllLEndo} p_{t,f}^{Fac}\left(1 - UnEmpRte_{t,f}\right)F_{t,f}^{supHou} + Transf_t^{Gov\rightarrow Hou} + \sum_s N_{t,s} Prof_{t,s}
\end{aligned}
$$

where δ is the assumed constant depreciation rate, and κ is a constant factor that converts the stock into a yearly flow of capital services so that, in terms of our previous notations, we have: $K_t/\kappa = F_{t,f}^{supHou}$, $f = KapHou$. The first term on the RHS is the flow income from renting capital; the second term is the value of the capital stock net of the period's depreciation. Observe that we are imposing the same price $p_t^{EuroInv}$ for new and old equipment, a simplifying though reasonable assumption. Observe also that p_{KapHou}^{Fac} is the same for all private physical capital owners within the EU - see equation (3) - so that the rate of return on physical assets would be equalised throughout Europe if the depreciation rates were the same for all regions.[16][17] All other terms in the equation have previously been introduced. Indeed, making use of our definition of Inc_r^{Hou} from (4), and of the assumption that the household's savings rate $SavR_{t,r}^{Hou}$ is constant, after some straightforward manipulations, we can rewrite the dynamic budget constraint more simply as follows:

$$
p_t^{EuroInv} K_{t+1} + p_t^{Gov} B_{t+1}^{Gov} = Sav_t^{Hou} + (1-\delta)p_{t-1}^{EuroInv}K_t + \left(1 + rint_{t-1}^{Gov}\right)p_{t-1}^{Gov}B_t^{Gov}
$$

[16] Depreciation rates are calibrated, and therefore differ between regions. It would be more theoretically consistent to assume in this equation a EU-average depreciation rate. Rates of return on physical assets would then be equalised within the EU, as implied by the assumption of perfect mobility of financial capital.

[17] Observe finally that though these two terms seem to implicitly define the user cost of capital, this is actually not the case, because p_{KapHou}^{Fac} is not the rental price paid by firms (which is $p_{t,f}^{Fac}$, $f = KapEur$, see equations (26) and (27)).

The market for local public bonds has been assumed to continuously clear at the current (though exogenous) interest rate $rint_t^{Gov}$, so that the amount of wealth held by households in the form of government bonds is determined by the public sector budget constraint. We collect the terms in B^{Gov} and make use of results derived from the public sector budget constraint to simplify the equation further as:

$$p_t^{EuroInv} K_{t+1} = (1-\delta) p_{t-1}^{EuroInv} K_t + Sav_t^{Hou} + Sav_t^{Gov}$$

Reintroducing foreign bonds into the household budget constraint, we get:

$$p_t^{EuroInv} K_{t+1} = (1-\delta) p_{t-1}^{EuroInv} K_t + Sav_t^{Hou} + Sav_t^{Gov} + Sav_t^{EU} + Sav_t^{RoW}$$

Using (43) yields the regions private sector capital stock accumulation equation:

$$p_t^{EuroInv} K_{t+1} = (1-\delta) p_{t-1}^{EuroInv} K_t + Sav_t$$

and the upgrading of the regions private factor supply of capital services writes as:

$$p_t^{EuroInv} F_{t+1,r,f}^{supHou} = (1-\delta) p_{t-1}^{EuroInv} F_{t,r,f}^{supHou} + \kappa Sav_{t,r} \qquad r \in R, \quad f = KapHou \tag{64}$$

which is the equation used in RHOMOLO. As previously mentioned in the text, all other factor endowments are constant.

3.11.2 THE DYNAMIC WAGE CURVE

Equation (60) represents the wage equation used in the static version of RHOMOLO. However, as suggested by Partridge and Rickmann (1998), wage dynamics should be accounted for in CGE models to better capture disequilibrium wage adjustments. To that end, real wages should not only depend on unemployment rates, as specified in equation (60), but also on the change in output prices and past real wages.

We use a dynamic wage equation that is able to generate short-run dynamics around the wage curve. The specification chosen is consistent with the wage setting described above. The dynamic wage equation is represented as follows:

$$\begin{aligned} log\left(\frac{p_{t,r,f}^{Fac}}{p_{t,r,f}^{Hou}}\right) = {} & a_r - \varepsilon_r \log(UnEmpRte_t) + \gamma_r\big(\log(p_{t,r}) - \log(p_{t-1,r})\big) \\ & (1-\lambda_r)\left(log\left(\frac{p_{t-1,r,f}^{Fac}}{p_{t-1,r,f}^{Hou}}\right) - \log(\tau_t)\right) \\ & -\theta_r(\log(UnEmpRte_t) - \log(UnEmpRte_{t-1})) \qquad f \in AllLEndo \end{aligned} \tag{65}$$

The real wage behaviour generates a sluggish adjustment towards the new steady state. Compared to the case of full wage flexibility, this specification introduces some rigidities and endogenous wage inertia. In practice, the difference with respect to a static wage curve, such as in equation (60), is that (65) takes into account not only the relation between wages and unemployment at a given period of time, but also the impact of past wages and changes in inflation and unemployment. In particular, real wages are positively affected by inflation and negatively affected by the levels and variations in unemployment rates.

For $\gamma = \lambda = \theta = 0$, the wage setting is represented by the conventional static wage curve whilst for $\gamma, \lambda, \theta > 0$ we are introducing a type of a dynamic adjustment over wage bargaining. In RHOMOLO, as default assumption, we do not account for productivity trend, therefore, we set τ_t=1.[18] The parameter λ_r allows one to shift from a wage curve to a Philips curve. For $\lambda_r = 0$ the wage adjustment implication of equation (60a) would be similar to an adjusted Phillip curve. On the contrary, for values less than 1, but greater than zero, some inertia is captured in the way real wages adjust in the model.

4 DATA SOURCES

4.1 NATIONAL SOCIAL ACCOUNTING MATRICES

As usual in CGE models, RHOMOLO data are organised in the form of Social Accounting Matrices (SAMs). The national SAMs are elaborated with public data sources available for 27 European countries.[19] The main data sources are World Input-Output Database (WIOD)[20] and Eurostat.

4.1.1 DATA SOURCES

In the elaboration of national SAMs, we have combined the information from WIOD with data from National Accounts and Eurostat. WIOD is one of the few databases that contain homogenised Input-Output information for the EU-27 and 13 other countries in the world (Timmer, 2012).

Eurostat provides also data on Supply and Use Tables (SUTs) and symmetric Input Output Tables (IOTs). However, they are not available for the same year in all countries, and there are methodological differences across countries. National Accounts provide consistent and detailed information on income distribution and government accounts. Hence, data of IOTs are directly obtained from WIOD, while figures on primary and secondary income distribution are collected from

[18] With estimates of productivity trend for all the regions represented in RHOMOLO we could in principle capture the full error correction element.

[19] Croatia has not yet been included due to the lack of data. Croatia will be included in the next update of the base year to 2013.

[20] WIOD is a project funded by the European Commission, Research Directorate General as part of the 7th Framework Programme, Theme 8: Socio-Economic Sciences and Humanities. Grant Agreement no: 225 281.

Eurostat. Eurostat data on value added and taxes have also been used as an additional source of information.

4.1.2 Construction of National SAMs

The original SAMs – elaborated for 27 EU countries – are balanced square matrices of size 85-by-85. They are aggregated in order to make them suitable for the RHOMOLO model.[21] In each economy there are three types of agents: households, government, and the foreign sector, which is divided into the EU and the ROW.[22,23] There are 59 productive industrial sectors, wages and employers' social contributions by skill level (high, medium and low) and an account for capital.[24] There are two accounts of taxes: direct taxes (households' income tax and corporate income tax), and taxes on production.[25] Additionally, SAMs contain current transfers,[26] an account for investment,[27] one for savings and three for trade and transport margins (specifically, trade and transport margins, re-exports, and international trade and transport margins). The last three accounts are explicitly included in WIOD in order to match the bilateral trade flows between countries.

The SAMs can be divided into different sub-matrices: the Intermediate consumption (input-output) matrix, the sub-matrices of value added (with labour and capital income, taxes paid by industries); imports; and the final demand matrix, which details the amount of goods demanded per product by households, government, investment, stock variations and exports. Finally, there are other sub-matrices that account for the redistribution of income, tax revenues and transfers.

A - Intermediate consumption

The intermediate symmetric IOT is a 59-by-59 homogenous product-by-product matrix at purchasers' prices elaborated with data from SUTs in WIOD. Symmetric IOTs provided by WIOD are industry-by-industry and they are valued at basic prices. Consequently, they cannot be combined

---

[21] More detailed information on the national SAMs is provided in Álvarez-Martínez and López-Cobo, 2016.

[22] In the original SAMs built with all the available information, there is a fourth agent, the corporate sector, which is an intermediate agent that pays and receives taxes and transfers. It does not consume and it is merged together with households.

[23] Since there are no specific data for Croatia, the trade information for this country is included in the account of the ROW.

[24] The original SAMs also include social contributions paid by employees, self-employed and unemployed.

[25] In the original SAMs taxes on products are also available.

[26] In the original SAMS this account is split into four types of transfers: property income, other current transfers, adjustments due to the participation of households in pension funds reserves and welfare benefits.

[27] Gross fixed capital formation and Stock variations.

with information from final demand in Use tables by products at purchasers' prices. Additionally, since the SAMs EU-27 are going to be used as a database to evaluate the impact of different public policies implemented by the European Commission, it seems more reasonable to construct product-by-product symmetric tables at purchasers' prices for all countries. The product-by-product transformation process applied here is based on the industry technology assumption detailed in Eurostat, which eludes the problem of negatives arising from the reallocation of secondary production.

In this process symmetric IOTs are compiled by post-multiplying the Use and Value added matrices, correspondingly, with a transformation matrix that reflects the industry-technology, Eurostat (2008). The construction process is as follows. First a transformation matrix is elaborated multiplying the inverse of the diagonal matrix of total production obtained from Supply tables by the Supply matrix. This transformation matrix is used in the construction of the input coefficients for intermediate demands and for the input coefficients of value added. These coefficient matrices are used to calculate intermediate demand values and also to disaggregate value added from 35 industries to 59 homogenous industries/products. In building this product-by-product matrix we are adjusting secondary production from the industries where they are really produced to the industries where they should be produced and that commodity is the principal product. Columns are transformed and in the new matrix they can be considered homogenous industries that produce one homogenous good mix.

The transformation of the symmetric table from basic prices to purchasers' prices implies to include net taxes on products associated with intermediate consumption in and also trade and transport margins, which are adjusted using a Cross Entropy Program (Robinson, Cattaneo and El-Said, 2000).

B - Value added and taxes

Value added is usually disaggregated into wages and salaries, employer's social contributions, gross operating surplus and other net taxes on production (NTP). The value added components that are available in the Socio Economic Accounts, in WIOD, are capital compensation, labour compensation – including wages received by self-employed- and compensation of employees. The figures of value added match the sum of labour compensation and capital compensation. NTP are not disentangled from previous accounts and they are merged with capital compensation. The disaggregation of value added into components is completed using more detailed data available in Eurostat[28][29]. This is

[28] Eurostat (2014). Annual national accounts: national accounts aggregates and employment by branch (NACE Rev. 1.1) 2008, 2009 and 2010 (nama_nace60_c) [Data file]. Downloaded on 2014 July 9. Available from http://ec.europa.eu/eurostat/data/database.

[29] Eurostat (2014). Supply, Use and Input-Output tables – ESA 1995 (NACE Rev. 1) 2005, 2006, 2007, 2008 and 2009 [Data file]. Available from http://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/data/workbooks.

the case for NTP and the disaggregation of compensation of employees into wages and salaries and employers' social contributions.

The disaggregation of wages and salaries and employers' social contributions by skill level is derived using WIOD data showing shares of labour compensation by skill level. These shares available for 2009 are applied to the compensation of employees in 2010.

Finally, a bi-proportional RAS adjustment procedure is used to match the total values by rows (value added components) and columns (industries).

C - Redistribution of income and transactions

The auxiliary accounts included in the SAMs capture the primary and second redistribution of income among institutional sectors. Primary factors income is redistributed among households, corporations, government and the foreign sector. Tax revenues and current transfers are also allocated following available data on National Accounts[30]. Eurostat does not provide information with this high level of disaggregation for all countries in the EU, therefore a number of assumptions are made to deal with missing data, lack of disaggregation and inconsistencies.

D - Final demand

The final demand matrix captures the amount of the total resources consumed by different agents in the economy and Investment (gross fixed capital formation and stock variations). The figures corresponding to these transactions are directly taken from the national Use Tables in WIOD at purchasers' prices. Exports constitute the final demand of the foreign sector. These data on exports to the EU-27 and the ROW are not directly available from WIOD because national SUTs do not provide any distinction by origin and destination. The data in the SAMs come from WIOD international SUTs. Exports can be calculated reversing the viewpoint of imports in international SUTs.

The aggregation of final demand by product and the intermediate demand from the symmetric IOT is equal to the total demand and it matches the total supply by product.

E - The foreign sector: imports and re-exports

Imports from the EU and the ROW together with value added and intermediate consumption add up to the total supply by product (industry). The data on imports are obtained from the WIOD international SUTs where they are valued at FOB prices. The FOB valuation has been used in WIOD in order to have coherent numbers of bilateral trade flows since any import is also an export for another country.

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[30] Eurostat (2014). Annual sector accounts: non-financial transactions 2010 (nasa_nf_tr) [Data file]. Downloaded on 2014 November 14. Available from http://ec.europa.eu/eurostat/data/database.

There is an account of re-exports that is part of the total supply. In WIOD re-exports are assumed not to be part of domestic production and their value has been subtracted from the total imports in CIF prices. The corresponding bilateral flows have been adjusted proportionally. All foreign trade flows are valued in FOB, which requires the introduction of a new account in the SAMs already estimated in WIOD named International trade and transport margins. This account captures the bilateral trade and transport margins by product category.

Non-residents' consumption is registered as a transfer from the foreign sectors to households and residents consumption abroad are included in the SAM as a transfer from the representative household to the foreign sectors. These data are taken from the WIOD SUTs. Hence, the column vector consumption accounts for commodity consumption in the country made by residents and non-residents.

4.2 INTERREGIONAL TRADE FLOWS

The *national supply and use tables* from the WIOD for 2010 provide the starting point for the construction of inter-regional trade flows for the whole EU at the regional level. The WIOD tables are adjusted such as to: (i) account for the distribution of re-exports over the origin and destination countries; (ii) ensure consistency in bilateral trade flows (i.e., that import trade flows are consistent with export trade flows); and (iii) ensure that exports and imports of all regions in each country add up to their national accounts totals as reported in the WIOD database.

As detailed in Thissen et al. (2015), the estimation of bilateral trade flows among all EU regions consists of two steps. In a first step, inter-regional SUTs for 240 NUTS2 regions are estimated using the constrained quadratic minimisation procedure by combining the regional SAMs (see section 4.3) and the Thissen et al. (2013) data on inter-regional trade flows as priors. The estimated inter-regional SUTs are fully consistent with the national WIOD tables, they contain consistent bilateral trade flows (import trade flows among the regions are consistent with the export trade flows).[31] In a second step, trade flows for the missing EU regions are estimated. The remaining NUTS2 regions, that are used in the RHOMOLO model but are not present in the Thissen et al. (2013) dataset of bilateral regional trade flows, are integrated into the 2010 inter-regional trade matrix. This is done by a proportional distribution of the gravity estimates of bilateral trade flows among the EU regions.

[31] Given that this estimation approach results in region-specific coefficients, it is conceptually different from the commonly used Isard (1953) Commodity Balance method for regionalisation.

4.2.1 ESTIMATION OF INTER-REGIONAL SUPPLY AND USE TABLES

Inter-regional SUTs for 2010 are estimated using the constrained quadratic minimisation procedure by combining the regional SAMs (see section 4.3) and the Thissen et al. (2013) data on inter-regional trade flows as priors (Thissen et al., 2013). In the first step, we use constrained non-linear optimisation to determine the intra-national regional trade among regions of the same country and the international trade of these regions with countries in the rest of the world. The non-linear quadratic objective function to be minimised in our non-linear optimisation problem describes how new information is used to compute the new matrices of trade flows, given the change in production and demand as reported in the national and regional accounts. In general, the required adjustments in the structure of the demand, supply and regional trade pattern is minimised, given new information on, for example, regional value-added and international trade. The complete minimisation problem can be described as follows:

$$Min\,\Omega = \sum_{r \in Cnt} \left[\left(\hat{\vartheta}_r^{col} - \vartheta_r^{col}\right)^2 + \left(\hat{\vartheta}_r^{row} - \vartheta_r^{row}\right)^2 + \left(\widehat{TrCost}_r - TrCost_r\right)^2 \right] + constraints$$

where, as above, index *r*, stands for the region, ϑ_r^{col} represents the elements of the regional SAM divided by its column total, ϑ_r^{row} represents the elements of the regional SAM divided by its row total, and $TrCost_r$ denotes the trade margins; for matters of convenience, we left out the summation over the elements of the SAM in this formula. The SAM is aggregated for all the imports from regions and countries except the regions from the own country. Thus, in this first step of the estimation procedure, only the intra-national trade and non-trade coefficients of the regional SAMs are computed. The international trade is determined in the second step of the procedure. As a consequence, the first step of the estimation procedure can be done for each country separately.

The objective function is constrained to generate outcomes conform to the regional and national SAMs. In addition to non-negativity, other imposed constraints are: (i) All elements summed over all regions in a country add up to the same elements in the national SAM. This constraint ensures that the regional SAMs are completely compatible with the WIOD database. (ii) All products sold by an economic agent are received and paid for by another economic agent. This bookkeeping rule is adhered to by imposing the equality of all row and column totals of the SAM for all activities (industries) and products. (iii) Value-added of the sectors in the regions are fixed, as this information is available from the data set. (iv) Information is also available on the regional total household demand and the regional total gross fixed capital formation: these items are therefore also fixed in the estimation procedure. (v) Finally, a 'no re-export' constraint is applied to ensure that production always exceeds exports, for every region and product. Note that, this constraint is imposed at the product level, not at the industry level. Solving the minimisation problem under these constraints results in an updated regional SAM, including intra-national trade.

In the second step, the international trade flows estimated above are subdivided into regions of destination and regions of origin, resulting in a full bilateral inter-regional origin–destination matrix of inter-regional trade flows. No additional information is available on these trade patterns, except on international trade flows among countries. Again, we use constrained non-linear quadratic optimisation to combine this information with existing trade patterns to determine the final estimates of trade flows among NUTS2 regions for 2010.

We apply a mixed objective function, where a quadratic absolute error $\widehat{ErrAbs_s}$ and a quadratic relative error $\widehat{ErrRel_s}$ are both minimised simultaneously. For this, two priors are taken into account: one is provided by the estimated trade flows from an export perspective (hereafter denoted $\widehat{Exp_{r',s,r}}$), and the other from an import perspective (hereafter $\widehat{Exp'_{r',s,r}}$). This yields the following objective function:

$$Min\ \Omega' = \sum_s \widehat{ErrRel_s} + \widehat{ErrAbs_s}$$

$$\widehat{ErrRel_s} = \sum_{r',r} \frac{1}{Exp_{r',r}} \left(\widehat{Exp_{r',s,r}} - Exp_{r',s,r}\right)^2 + \sum_{r',r} \frac{1}{Exp'_{r',r}} \left(\widehat{Exp'_{r',s,r}} - Exp'_{r',s,r}\right)^2$$

s.t. $$\widehat{ErrAbs_s} = \sum_{r',r} \frac{1}{\overline{Exp_{r'}}} \left(\widehat{Exp_{r',s,r}} - Exp_{r',s,r}\right)^2 + \sum_{r',r} \frac{1}{\overline{Exp'_r}} \left(\widehat{Exp'_{r',s,r}} - Exp'_{r',s,r}\right)^2$$

$$Exp_{Cnt',s,Cnt} = \sum_{r' \in Cnt', r \in Cnt} \widehat{Exp_{r',s,r}}$$

$$Exp'_{Cnt',s,Cnt} = \sum_{r' \in cnt', r \in cnt} \widehat{Exp'_{r',s,r}}$$

in which $Exp_{Cnt',s,Cnt}$ denotes exports of country Cnt' destined for country Cnt (directly taken from the WIOD tables) and $Exp'_{Cnt',s,Cnt}$ denotes imports by country Cnt from country Cnt' (also directly taken from the WIOD tables). Variables $\overline{Exp_{r'}}$ and $\overline{Exp'_r}$ denote the average values of exports to region r', and imports in regions r, respectively. The estimation of inter-regional trade flows is performed on the importing sector level, s, and thereby completely consistent with the WIOD tables. The priors of exports (imports) are determined by the regional trade pattern of exports (imports) from Thissen et al. (2013). Note that we define the quadratic relative error slightly differently than in percentages. The reason is related to the weight of both errors in the objective function. In the above specification, both weights are equal, because the sum of trade among all regions, $Exp_{r',r}$is equal to the sum over all regions of the average value of the trade, $\overline{Exp_{r',s}}$.

4.2.2 Estimating trade flows for the missing regions

In a final step, 30 NUTS2 regions that are missing in the Thissen et al. (2013) dataset are added to the above estimated trade flows for 240 NUTS2 regions to complete the inter-regional bilateral trade dataset for the EU27. The missing regions are all regions in Romania, Bulgaria and Slovenia. Slovenia was recently split into two regions and therefore still presented as one region in the Thissen et al. (2013) database. Additionally, the islands of Portugal are included in the above constructed trade flows, and the regional aggregation in Denmark was changed into a different regional classification.

The same methodology as described above is used to construct bilateral trade flows for these regions missing in the Thissen et al. (2013) dataset. In all cases, the trade flows data are already available at the country level. Thus, all regions available in the Thissen et al. (2013) database already traded with all EU Member States. We only have to subdivide this trade over the different regions in these countries. We use the shares from the gravity-based estimates of inter-regional trade flows to estimate the trade flows for these regions. Thus, for example, trade from Andalusia to Romania is subdivided over the Romanian regions according to the proportions taken from the gravity-based estimates (for details see Thissen et al., 2014). Exactly the same approach is followed to subdivide the imports. Finally, the internal trade among the missing regions from the same country is subdivided according to the trade patterns in the gravity-based estimates of inter-regional trade flows (see Thissen et al., 2014). For example, the proportions of intra-national trade are obtained by dividing the Romanian intra-national trade from the gravity-based estimates of inter-regional trade flows by the total Romanian intra-national trade database. The intra-national trade in the new database is subsequently obtained by this matrix of proportions with the intra-national trade as given in the WIOD database (see Thissen et al., 2014).

4.3 Construction of regional SAMs

The national SAMs are subsequently regionalised by means of non-survey techniques using the available regional statistical data from Eurostat and inter-regional bilateral trade flows from Thissen et al. (2015).

4.3.1 Data sources

The original SAMs elaborated for the 27 EU countries are balanced square matrices of 85-by-85. Data relative to the productive sectors are compiled according to NACE[32] Rev. 1. The availability of

[32] Statistical classification of economic activities in the European Community.

Regional Accounts statistics from Eurostat at NUTS2 level is limited. The available data at the region-sector level include:[33]

- Value added (VA).[34]
- Gross fixed capital formation (GFCF).[35]
- Compensation of employees (COMP_EMPL).[36]

The available data at the regional level include:

- Allocation of primary income account of households: Property income paid and received (PI_p and PI_r).[37]
- Secondary distribution of income account of households: Social benefits other than social transfers in kind received (WFB_r), Other current transfers paid and received (TR_p and TR_r), Current taxes on income paid (DTX_p), Social contributions paid (SSCHSU_p) and Net disposable income (NDI).[38]

The inter-regional trade flows (see section 4.2) are used as a trade constraint for the regionalisation of national SAMs. A number of adjustments were needed to make the trade flows consistent with the national SAMs and regional estimates. All regional data are currently available from Eurostat according to the NUTS2010 classification. All sectoral data referring to 2010 are available according to NACE Rev. 2. However, the national SAMs were constructed mainly from WIOD, which was built when NACE Rev. 1 was in use. Furthermore, RHOMOLO is being used intensively for the impact assessment of the EU Cohesion Policy, and the regions for which the Cohesion Funds are allocated are those existing according to the NUTS2006 classification. Therefore, the regional SAMs for RHOMOLO are built according to the NUTS2006 and NACE Rev. 1 classifications.

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[33] At the time of writing this report, these datasets (built according to the European System of Accounts 1995) are not available anymore. They have been substituted by equivalent datasets under the European System of Accounts 2010, with names: nama_10r_3gva, nama_10r_2gfcf and nama_10r_2coe respectively.

[34] Eurostat (2015). Regional economic accounts– ESA95. Gross value added at basic prices by NUTS 3 regions 2010 (nama_r_e3vab95r2) [Data file]. Downloaded on 2015 July 27. Available from http://ec.europa.eu/eurostat/data/database.

[35] Eurostat (2015). Regional economic accounts– ESA95. Gross fixed capital formation by NUTS 2 regions 2010 (nama_r_e2gfcfr2) [Data file]. Downloaded on 2015 July 27. Available from http://ec.europa.eu/eurostat/data/database.

[36] Eurostat (2015). Regional economic accounts– ESA95. Compensation of employees by NUTS 2 regions 2010 (nama_r_e2remr2) [Data file]. Downloaded on 2015 July 27. Available from http://ec.europa.eu/eurostat/data/database.

[37] Eurostat (2015). Regional economic accounts– ESA95. Allocation of primary income account of households by NUTS 2 regions (nama_r_ehh2p)[Data file]. Downloaded on 2015 July 27. Available from http://ec.europa.eu/eurostat/data/database.

[38] Eurostat (2015). Regional economic accounts– ESA95. Secondary distribution of income account of households by NUTS 2 regions (nama_r_ehh2s) Downloaded on 2015 July 27. [Data file]. Available from http://ec.europa.eu/eurostat/data/database.

4.3.2 METHODOLOGY FOR REGIONALISATION

The regionalisation of national SAMs is a 4-stage process, which is based on a non-survey commodity-balance method. First, the national SAMs are aggregated from 59 to 5 sectors plus R&D. Second, regional data are imported and tested, missing values are imputed and data are converted from NUTS2010 to NUTS2006. Third, a first estimate of regional SAMs is computed with the available information, including the R&D sector. Finally, bilateral trade-flows are adjusted to fit the regional supply-demand balance. [39]

The symmetric IOT of national SAM contains 59 homogenous sectors. However, regional data are only available at an aggregate level (six sectors available for all regions). As a consequence, national SAMs have to be aggregated before regionalisation. Although an overall comparison between NACE Rev. 2 and NACE Rev. 1 is not possible, the aggregation into five or six macro-sectors for RHOMOLO minimises the impact of changes in the structure. Table 1 shows the correspondence between the six macro sectors and the NACE codes for both Rev. 1 and Rev. 2, as well as with respect to the 59 sectors in the original national SAM.

Table 1: Broad correspondence of RHOMOLO macro sectors

Sector acronym	*Sector description*	*NACE Rev. 1 codes*	*NACE Rev. 2 codes*	*Sectors in national SAM*
Agricul	Agriculture, hunting, forestry + Fishing	AB	A	1-3
ManuCon	Mining and quarrying + Manufacturing + Electricity and Gas	CDE	BCDE	4-33
	Construction	F	F	34
TrTrade	Wholesale and retail trade; repair of motor vehicles, motorcycles + Hotels and restaurants + Transport + Communications	GHI	GHIJ	35-43
BusServ	Financial intermediation + Real estate and business services	JK	KLMN	44-51
	(R&D)			*(50)*
OthServ	Non-Market Services	LMNOP	OPQRSTU	52-59

In principle, the regional SAMs can be developed with six sectors plus R&D. However, the consequences of the economic crisis on the construction sector investments in our baseline year (2010) make it advisable to aggregate it with the manufacturing sector to avoid distortions in model output.

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[39] A more detailed description of the regionalisation for the EU-27 and its extension to the EU-28 is provided in López-Cobo, 2016.

The R&D sector is isolated from the BusServ sector, where it is embedded in the national SAMs. First, the R&D sector is treated as any other sector, meaning that it contains data on all factors, taxes, trade and so on. In a second step, the regional R&D sector is simplified to labour inputs only.

All regional data are extracted from the Eurostat website. Consistency checks are carried out in order to assess data quality and improve when necessary. Overall, the quality of regional data seems to be satisfactory, although minor inconsistencies and missing values persist. Any inconsistent data are individually controlled for and missing sectoral disaggregation is imputed from country-level data weighted by regional shares.

The only classification for which regional data are available from Eurostat is NUTS2010.[40] Therefore, for those regions that have experienced change in the classification (merge, split or shift boundaries), regional data need to be converted by aggregating or splitting the current data. In addition to those regions changing NUTS codes (all Greek and some Italian regions), there are 11 NUTS2006 regions (or 10 NUTS2010 regions) affected by these changes. There are three types of changes and each of them needs to be addressed differently:

- For merged regions from 2006 to 2010: to reproduce NUTS2006 data, NUTS2010 data are disaggregated using GDP shares of the regions existing in 2006;[41]
- For split regions from 2006 to 2010: NUTS2010 data are aggregated;
- For boundary shifts: first, data are aggregated and later disaggregated using estimated GDP shares of the regions existing in 2006.

The estimation of regional SAMs consists of the estimation of value added components by sector, intermediate demand by sector, final demand by product, imports and exports by product, and

[40] Every time the NUTS classification is being updated (usually every three years), all regional data are released only using the new classification, backwards time series are provided and series according to the old classification are deleted from Eurostat website.

[41] To that end we have used available data on GDP according to NUTS2006 in 2009 at NUTS2 level and according to NUTS2010 in 2010 at NUTS3 level: A mapping procedure has been put in place to estimate 2010 GDP of regions existing under NUTS2006 and not under NUTS2010. The following datasets have been used:

Eurostat (2014). Regional economic accounts– ESA95. Gross domestic product (GDP) at current market prices by NUTS 3 regions 2010 (ESA95, NUTS 2010) (nama_r_e3gdp) [Data file]. Extracted on 2014 October 1. Available from http://ec.europa.eu/eurostat/data/database.

Eurostat (2014). Regional economic accounts– ESA95. Gross domestic product (GDP) at current market prices by NUTS 2 regions 2010 (ESA95, NUTS 2010) (nama_r_e2gdp) [Data file]. Extracted on 2014 July 29. Available from http://ec.europa.eu/eurostat/data/database.

Eurostat (2013). Regional economic accounts– ESA95. Gross domestic product (GDP) at current market prices by NUTS 2 regions 2009 (ESA95, NUTS 2006) (nama_r_e2gdp) [Data file]. Extracted on 2013 February 27. Not available anymore in the Eurostat webpage.

transfers among agents. In a first step, the value added (VA) is estimated using a bi-proportional RAS algorithm to match the data available by region and sector. The constraints are: a) the sum by region - or sector marginal target - must coincide with national VA by sector (from the national SAM); b) the sum by sector - or region marginal target - is given by the estimation of the regional VA Total, i.e. national VA Total (from the national SAM) multiplied by regional VA shares (from Eurostat). The prior matrix used is the original regional VA data from Eurostat.

By imposing the national sectoral distribution from the national SAMs (NACE Rev. 1), the sectoral regional data are re-weighted and thus transformed from NACE Rev. 2 to the NACE Rev. 1 classification.

Secondly, the VA is decomposed in two stages into the four components of VA in the SAMs, namely:

- Compensation of employees (COMP_EMPL):
    - Wages and salaries (WS);
    - Employer's social contributions (SSCE).
- Gross operating surplus + Other net taxes on production (GOS + NTP).

The same approach as for estimating VA is applied to obtain regional estimates of Compensation of employees (COM_EMPL) by sector. Residually, GOS + NTP = VA - COMP_EMPL.

It is assumed that the regional VA composition maintains the national distribution, that is, the ratio between WS and SSCE over COMP_EMPL is the same as in the national SAM, for each skill level: high, medium, and low. Similarly, GOS + NTP is disaggregated into its two components.

For the estimation of regional total output, we impose the assumption that the ratio VA/Output is constant across regions and equal to the ratio in the national SAM.

For the estimation of regional intermediate input matrix, national technical coefficients are applied. For each region *r* and sector *s*, the intermediate input to total output ratio is kept constant across regions and equal to the ratio in national SAM.

Finally, net taxes on products are computed maintaining national ratios over total output.

In order to estimate household demand, data on regional net disposable income (NDI) are used as a proxy of household demand, assuming that savings and consumption behaviour of consumers within country follow the same pattern and are independent of income levels (i.e. their preferences are considered homothetic as is the case in the model). More precisely, regional household demand is obtained by multiplying national household demand by the regional share of NDI. Government demand is estimated as a proportion of household demand: the ratio is assumed to be constant across regions and equal to the national ratio. In order to estimate gross fixed capital formation (GFCF), regional data on GFCF are used to produce regional estimates. As with value added and compensation of employees, where regional data from Eurostat are available, a bi-proportional RAS algorithm is applied to fulfil the constraints imposed by national sectoral data and regional shares.

Stock variations are estimated as a proportion of regional GFCF, we assume the ratio constant across regions and equal to the national ratio.

The bilateral inter-regional trade matrix of imports and exports from/to the EU (see section 4.2) is adjusted such that country trade totals are satisfied.[42] This is done by a generalised RAS method, which keeps the structure of bilateral trade flows as much unchanged as possible. Imports from ROW are regionalised by keeping the ratio between imports from EU and from ROW constant. Exports to ROW are regionalised by keeping constant the ratio between exports to ROW and Output, therefore respecting the constraint that exports come from the domestic supply. Re-exports and international trade margins are regionalised by keeping their shares in imports from EU constant and equal to that observed at the national level.

In order to estimate intra-region transfers among agents, regional data from Eurostat are used (PI, DTX, WFB…) in the form of regional shares applied to national values. For the rest, it is assumed constant ratios with respect to other informed regional data.

Transfers from/to EU and ROW are estimated as follows. For the compensation of employees (WS, SSCE), payments from the foreign sector are assumed to have the same ratio as domestic payments observed at the national level. For the transfers received by the foreign sector, first, column totals for WS and SSCE are computed (from the previous step), and then distributed among agents - HH, GOV, EU and ROW - according to national shares. A similar approach is used for SSCHSU (Social contributions), PI (Property income), DTX (Current taxes on income, wealth, etc.), TR (Other current transfers), NTP (Other net taxes on production), NTPR (Net taxes on products) and WFB (Social benefits other than social transfers in kind).

Regional R&D sector is implemented at the national level, though R&D services are consumed regionally. It uses only high-skill labour (WS_h) and is demanded by all the other sectors as intermediate inputs. To regionalise the labour demand of the R&D sector, the national R&D high-skill labour factor is multiplied by the regional share of VA of sector BusServ (comprising the R&D sector). To regionalise the intermediate inputs of R&D by other industries, the former figure is distributed among sectors following the sectoral shares of intermediate use of R&D products at the national level.

The regional SAMs built with this methodology add up to the national SAM. Some balancing is nevertheless necessary, because each individual regional SAM may be unbalanced, with excess supply from one region being compensated by excess demand in another region of the same country. The assumption is made that inter-regional trade flows need to be re-adjusted. An

[42] The disarrangement between country trade totals in national SAMs and inter-regional trade matrix arises because re-exports are corrected before estimating bilateral trade flows (section 4.2). As a consequence, total imports and exports by country are changed with respect to those in WIOD's national SUT used to build the national SAMs.

algorithm is used to redistribute trade among the regions for the three flow types: within the country, with the rest of EU and with the rest of the world, with the constraint of keeping country totals by flow type unchanged. An extra constraint of not allowing zero imports or exports is added, which was the case for a reduced number of regions/sectors in the original Thissen et al. (2015) data set. Lastly, this algorithm ensures that the domestic part of absorption, or the diagonal elements of the bilateral trade matrix, is always positive so as to avoid inflating re-exports (which are goods that are imported by and exported from a region, without any transformation or added value in the process).

4.4 HERFINDAHL INDICES

The number of firms in each sector-region is empirically estimated through the national Herfindahl indices, assuming that all the firms within one region share the same technology. The Herfindahl-Hirschman Index (HHI) is the most widely used summary measure of concentration in the theoretical literature (Bikker and Haaf, 2002). It takes the form $\mathrm{HHI} = \sum_{i=1}^{N} s_i^2$, where N is the number of firms and $s_i = q_i/Q$ is the share of firm i in the total Q (Q might represent aggregate output or turnover, or some other industry aggregate). The HHI is often called the full-information index because it captures features of the entire distribution of firm sizes and hence, it is very data demanding. We have computed an approximation to the HHI at the national level for the EU27 using official statistics from Eurostat. By relying on official statistics, we are able to avoid problems regarding data availability. The main drawback is that we need to use aggregated data, since there are no data at individual firm level in Eurostat. Under the assumption of symmetry, the inverse of HHI is the number of equally sized firms with same level of concentration. Therefore 1/HHI is used as a measure of the number of symmetric firms in RHOMOLO.

4.4.1 DATA SOURCE, ASSUMPTIONS AND COMPUTATION

The main data source is *Structural business statistics (SBS)* published by Eurostat. SBS describes the structure, conduct and performance of economic activities, down to the most detailed activity level. SBS covers all activities of the business economy with the exception of agricultural activities and personal services and the data are provided annually by all EU Member States. Information for the financial sector is not always available. We use SBS for 2007, the most recent year for which data according to NACE Rev 1.1 are available. Data exist for all sectors from C to K except J (financial sector). SBS provide information on business demographics (e.g. number of enterprises), output related variables (e.g. turnover) and input related variables (employment, total of purchases, etc.). Data are broken down by size classes, referring to the number of persons employed in the firm, into five classes for sectors C to F and six classes for sectors G to K.

The share of firms can be computed using three different measures of performance at the sector level: i) turnover or gross premiums, ii) value added at factor cost, and iii) number of persons employed. We have used the output variable *turnover*; which showed slightly lower missing data rates. To properly apply the formula we would need to have individual information on turnover for all the firms. Instead, we have data for the firms grouped 5 size classes (hereafter indexed *k, k'*= 1 to 5).

We assume that the N_k firms have the same turnover equal to the average turnover in the class *k*: $t_k = T_k/N_k$, where T_k is the aggregated turnover of the size class *k*, $T_k = \sum_{i=1}^{N_k} t_i$. Hence, the share of each individual size-class *k* firm in total sector turnover is identical, and equal to:

$$s_k = \frac{t_k}{\sum_{i=1}^{N} t_i} = \frac{\frac{T_k}{N_k}}{\sum_{k'=1}^{5} T_{k'}} = \frac{1}{N_k}\frac{T_k}{\sum_{k'=1}^{5} T_{k'}}$$

We can then compute HHI using SBS data by size class:

$$HHI = \sum_{i=1}^{N} s_i^2 = \sum_{k=1}^{5} N_k\, {s_k}^2 = \frac{1}{T^2}\sum\nolimits_{k=1}^{5}\frac{T_k^2}{N_k}$$

where $T = \sum_{k=1}^{5} T_k$ is the total aggregated turnover of all firms. Following this method, HHI is computed for the EU27 countries at the aggregated sector level (3 monopolistically competitive sectors: *ManuCon*, *TrTrade*, *BusServ*).

Table 2: Available information from SBS at size class level and assumptions made for the computation.

	Size class (k)
Available data in SBS	Aggregated turnover: T_k Number of firms: N_k
Assumption: All firms in class *k* have same turnover	Individual class *k* firm turnover: $t_k = \frac{T_k}{N_k}$
Consequence: All firms in class *k* have same share in sector aggregate	Individual class *k* firm's share in sector aggregate: $s_k = \frac{t_k}{\sum_{k'} T_{k'}}$

4.4.2 CONFIDENTIALITY ISSUES, MISSING VALUES AND IMPUTATION

SBS statistics are constrained by confidentiality, especially important at the most disaggregated level of economic activity, where many cells could refer to 1 or 2 statistical units (enterprises). For this reason, a relatively high percentage of cells show missing values. For example, around 13% of the values for the indicator "number of enterprises" is missing; this percentage reaches an average of 27% for the indicators "turnover", "value added" or "number of persons employed". These cells are reported empty by the statistical authorities in order to avoid potential individual identification. At aggregated level of economic activity (1 digit: C to K), the percentage of missing values decreases until 6,4% on average, but shows great variability among sectors, ranging from 22,2% for sector C (Mining), to less than 1% for sectors G, H, I and K.

To apply the HHI formula developed above, first the missing values needed to be imputed. With this aim, data are split into two groups per each SBS indicator (turnover, value added and number of persons employed) and sector: countries where all size categories have valid data (group A) and countries where at least one size category has a missing value (group B). Group A is used to compute average frequency percentages of each size category, which are later applied to obtain the missing values in group B. Averages are computed per each SBS indicator by sector.

4.5 ADOPTED VALUES FOR ELASTICITIES

4.5.1 HOUSEHOLDS

A. Transformation elasticity between the R&D and non-R&D high-skill labour supply: $\sigma_r^{FacSupLab-H} = 1.0$

The PREDICT model (see Christensen 2015) is rather similar to RHOMOLO both in terms of modelling of R&D and in terms of the sectoral disaggregation. Therefore, for the elasticity of transformation between the R&D and non-R&D high-skill labour supply, we use the value of Christensen (2015), which is 1.0.

B. Elasticity of substitution between different consumption goods: $\sigma_r^{Con^{Hou}} = 1.2$

In terms of the sectoral disaggregation, the closest model to RHOMOLO is PREDICT: it also has 5 industrial sectors plus an R&D sector (Christensen 2015). Therefore, for the elasticity of substitution between consumption goods from different sectors, we adopt the same value of 1.2.

4.5.2 FIRMS

A. Elasticity of substitution between primary factors and intermediate inputs: $\sigma_{r,s}^{Z} = 0.2$

For the substitution elasticity between primary factors and intermediate inputs, $\sigma_{r,s}^{Z}$, we borrow the value from Capros et al. (2013) for the GEM-E3 model of 0.2. The GEM-E3 elasticities are mostly based on the econometric estimates provided in Koschel (2000), who estimate the elasticities between capital, labour and materials for the German economy.

B. Elasticity of substitution between different intermediate goods: $\sigma_{r,s}^{X} = 0.25$

The same source provides the value of 0.25 for the elasticity of substitution between different intermediate goods, $\sigma_{r,s}^{X}$ (Capros et al., 2013).

C. Elasticity of substitution between aggregate labour and capital: $\sigma_{r,s}^{Q} = 1.0$

The Cobb-Douglas assumption has received substantial empirical support in the literature (see Balistreri et al., 2003, for example, who failed to reject the Cobb-Douglas specification for the vast majority of industries in the US). We therefore set unity as default value for $\sigma_{r,s}^{Q}$.

D. Elasticity of substitution between private and public capital: $\sigma_{r,s}^{Kap} = 2$

In a CGE model with R&D-driven technological change Bye et al. (2006) use values for the elasticity of substitution between different capital varieties in a range 1.5 to 3.0. These elasticities are surprisingly high. We adopt a value within this range, specifically 2.

E. Elasticity of substitution between different skill groups: $\sigma_{r,s}^{Lab} = 1.5$

The empirical literature provides a range of values for the elasticity of substitution parameter $\sigma_{r,s}^{Lab}$, most commonly distinguishing between a high- and a low-skill-labour. In an influential study, Card and Lemieux (2001) have estimated the elasticity of substitution between American college and high school graduates and find values ranging from 1.1 to 1.6. Katz and Murphy's (1992) findings are in line with this range, as they report an elasticity of 1.41. Krussel et al. (2000) also report a value within that range as they find an elasticity of 1.67.

F. R&D spillovers: the knowledge externality parameter: $KnowK^{Ext} = 0.53$

The elasticity of the technology parameter to changes in the stock of knowledge capital, $KnowK^{Ext}$, is assumed to be equal to 0.53, in line with the empirical results of Bottazzi and Peri (2007) on domestic R&D spillovers to productivity. This value is used also by QUEST for the effect of the accumulation of domestic knowledge stock on firm productivity (Varga and in 't Veld, 2011), in addition to an international spillover value of 0.45, also estimated by Bottazzi and Peri (2007). Parameters in a similar scale are used by GEM-E3 for (0.18 to 0.44) for the "Learning by research" spillover rates for specific sectors such as clean energy production (Karkatsoulis et al., 2014).

4.5.3 The Government

The elasticity of substitution between different consumption goods: $\sigma_{r}^{Gov} = 0.3$

The composition of the government's consumption basket is often assumed fixed (e.g. Bye et al., 2006) to reflect the perception that public authorities are quite unresponsive to price changes. Though in the very short run this might be reasonable, it seems somewhat extreme considering the time horizon of interest of RHOMOLO (10 to 20 years). We therefore make a less extreme characterisation of the public sector consumption behaviour and set the base value of this elasticity to $\sigma_{r}^{Gov} = 0.3$.

4.5.4 Investment and Capital

At the upper level of the investment technology: $\sigma^{EuroInv} = 3$; Elasticity of transformation of EU capital between regions $\sigma^{EuroKap} = 3$

With physical capital being mobile - albeit imperfectly - between regions, it is necessary to simplify the book-keeping of asset holdings by defining a single-priced EU aggregate investment good, the structure of which should reflect both base year composition data and responsiveness to relative cost changes. The values of $\sigma^{EuroInv}$ and $\sigma^{EuroKap}$ command the relative emphasis placed on these two considerations. We have adopted, conservatively though somewhat arbitrarily, the value of 3, which is equal to the value assumed for $\sigma_{Cnt,RnD}^{Arm}$ in R&D mark-up equation (51), but keep these parameters in mind when running systematic sensitivity analyses on model results.

At the lower level of the investment technology: $\sigma_r^{Inv} = 1.3$

Typically, CGE models in the literature use values in the range 1.0-1.5 (Bye et al., 2006; Gelauff and Lejour, 2006; Christensen, 2015; Karkatsoulis et al., 2014). In RHOMOLO we use an elasticity which is between the minimum and the maximum values used in the literature.

4.5.5 TRADE

Elasticities of substitution between goods from different regions: $\sigma_{r,s}^{Arm} = 6.0$

Elasticities of substitution between goods from different regions are hard to come by. In RHOMOLO, $\sigma_{r,s}^{Arm} = 6.0$ is chosen as base value following the econometric work of Felbermayr et al. (2014). This is in the higher range of what is commonly used in the literature for perfectly competitive sectors, but as is well known, higher values are necessary for very geographically disaggregated models such as RHOMOLO in order to avoid spurious terms of trade effects (see e.g. McDaniel and Balistreri, 2003). Since the choice of the value of the Armington elasticity is an important driver of the model's outcome, it will be subject to substantial sensitivity analysis.

4.5.6 WAGE CURVE

Wage curve elasticity (in absolute terms): $\varepsilon_r^{wagecurve} = 0.1$

A key parameter driving the effect of shocks on the regional unemployment is the wage curve elasticity. In the static version of RHOMOLO, the slope of all regional wage curves is assumed to be equal to -0.1, a commonly recurring value in the empirical literature (Card, 1995; Blanchflower and Oswald, 1995; Janssens and Konings, 1998; Fagan et al., 2005).

In the static version of RHOMOLO, the wage curve is estimated for each country using aggregate regional wages (averaged at the regional level) and regional unemployment. This implies that identification of the wage curve coefficient is based on within-country regional variation and time variation in aggregate regional wages, regional workforce characteristics and the regional unemployment rate. As for the implementation of the wage curve in RHOMOLO, we impose that at the wage observed in the base year 2010, the wage curve implies the base-year unemployment rate. The base-year wage is normalised to 1. The base-year unemployment rate is taken from the

Eurostat's Labour Force Survey (LFS) based data series *lfst_r_lfu3rt*. Then, we impose that changes in the unemployment-rate lead to iso-elastic changes in the wage (or vice-versa), with an elasticity of -0.1 (which corresponds to what is typically found in the empirical literature in a wide variety of countries, see e.g. Nijkamp and Poot, 2005).

5 CALIBRATION

The calibration of the model is done using the regional SAMs and inter-regional trade flows for 2010 as benchmark. Prices are defined as indices and most of them can therefore be assumed equal to unity at the initial equilibrium, so that value flows available from the SAM actually provide information on quantities. All this is quite standard, and need not be detailed here: see e.g. Mansur and Whalley (1983).

The only nonstandard aspect of our calibration procedure is related to imperfectly competitive industries. The difficulty here is that prices cannot all be set to unity –as should be obvious from the firm's pricing equation (10)– so that the equilibrium price and quantity systems must be determined jointly in those industries: see Mercenier (1995a). Here is how we proceed. In what follows, a "~" over a variable denotes a base year flow at current prices, with value therefore known from the data set.

The (r,s)-firm's market shares are known from the base year bilateral trade matrix: from (13) we have:

$$MSh_{r,s,r'} = \frac{\left(1 + TxR^{Z}_{r,s}\right)\widetilde{Exp}_{r,s,r'}}{\widetilde{Arm}_{r',s}} \quad , \quad r' \in AllR \tag{C1}$$

so that the base year bilateral specific Lerner index can be determined from (11) or (12). It then follows that the firm's optimally discriminating spread of prices can be determined, conditional on the yet unknown marginal production cost:

$$\frac{p^{Exp}_{r,s,r'} - Ma^{Cost}_{r,s}}{p^{Exp}_{r,s,r'}} = Lerner_{r,s,r'} \quad , \quad r' \in AllR. \tag{C2}$$

The volume of sales on each individual market then follows from:

$$p^{Exp}_{r,s,r'} Exp_{r,s,r'} = \widetilde{Exp}_{r,s,r'}.$$

Summing these yields the total market demand for the firm's good:

$$Z_{r,s} = \sum_{r' \in AllR} Exp_{r,s,r'} \tag{C3}$$

with average selling price:

$$p_{r,s}^{Z} Z_{r,s} = \sum_{r\prime \in AllR} \widetilde{Exp}_{r,s,r\prime}.$$

The firms technological constraints imply both the (yet undetermined) marginal and fixed costs of production; the two jointly contribute to determine the firm's average cost:

$$Av_{r,s}^{Cost} Z_{r,s} = Ma_{r,s}^{Cost}\left[Z_{r,s} + Fx_{r,s}^{Cost}\right] \quad \text{(C4)}$$

The zero profit assumption links the average cost to the average sales price:

$$p_{r,s}^{Z} = Av_{r,s}^{Cost} \quad \text{(C5)}$$

We can normalise $p_{r,s}^{Z}$ to unity. Solving the system (C1) to (C5) yields the individual firm's level of both marginal and fixed costs consistent with optimal price discrimination as well as with the statistical information available on its sales on each regional client market.

6 Conclusions

In this report, we have presented the spatial dynamic general equilibrium model RHOMOLO, developed to undertake the ex-ante impact assessment of EU policies and structural reforms. An important element of RHOMOLO is the taking into account of a rich set of spatial interactions, introduced by means of an asymmetric transport cost matrix derived from the transport model TRANSTOOLS[43]. Transport costs are not just specific to individual sectors and region-pair combinations, but also depend on the direction in which goods are transported. This captures the importance of space as a determinant of regional economic performance. The existence of transport costs triggers agglomeration and dispersion forces, through the availability of cheaper intermediates, access to consumers and degree of competition.

Trade flows and economic performance of regions are not shaped only by exogenous transport costs and region-pair specific taste parameters. Another distinctive feature of the model is in fact the presence of a sophisticated modelling of market interactions, which are more general than what is usually assumed in most computable general equilibrium models and rely on a theoretically robust framework. Specifically, the different nature of market interactions in different sectors of the economy is acknowledged by allowing for different degrees of competition based on empirically observed levels of firm concentration (i.e., if a particular sector is found to be spatially concentrated in the data, this is translated into higher firm-level mark-ups). RHOMOLO's labour markets are characterised by unemployment, which is endogenised by means of a wage curve. Finally, the introduction of an inter-regional R&D sector associated with technological spill-overs brings into the

[43] http://energy.jrc.ec.europa.eu/transtools/

model the well-documented evidence that economic systems are not suspended in the void, but interact with their external environment only market interactions (captured by the standard mechanisms of the model) and through non-market interactions, which are often outside the scope of theoretical models although acknowledged in empirical studies.

As any large scale macro-economic model, RHOMOLO is constantly "works in progress", where the availability of new data, improved theoretical foundations, new evidence or better estimates of elasticities and exogenous parameters are always associated with incremental improvements. This report can thus be seen as a snapshot of the current state of the art of the model and it can serve as reference and benchmark for the future versions. Of course, given the unlimited possibilities of evolution of the RHOMOLO model (such as income distribution across households, different sources of firm and consumer heterogeneity, non-homothetic utility functions), several guiding principles are followed in RHOMOLO to focus the efforts and narrow down the scope of additional modules and variations. From our interactions with scientific community and policy stakeholders, we have attempted to follow the following principles in the development of a reliable policy-oriented modelling tool RHOMOLO:

- Scientific credibility: both the data used and the modelling choices adopted are in line with state-of-the-art literature or otherwise very carefully documented and explained, performing robustness checks and sensitivity analyses, and scrutinised by the scientific community through publications in renowned field journals;
- Saliency: beyond technical feasibility, the model is evolving also in the direction of answering and guiding relevant policy questions, interacting at the same time with policy makers and the scientific community;
- Legitimacy: all the potential stakeholders of the research activity are permanently kept informed, they provide inputs and suggestions for the improvement of the model, in order to maximise the impact of research on policy and facilitate the interaction between the scientific community and the rest of society.

In order to adhere to these principles, while at the same time exploring new modelling possibilities, a constant effort of maintaining and fine-tuning the model is undergone by the Regional Economic Modelling team. Even if the constant evolution and refinement of the model may sometimes bemuse the end users of the model's results, it should be understood as an integral part of the process of having a general equilibrium model ready to be deployed to answer new policy questions and support policymaking.

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8 APPENDICES

8.1 SETS, SUBSETS AND INDICES

- Territorial units: subscripts *r* or *r'*

AllR defines the set of all territorial units; this set is partitioned into two subsets, the subset of all regions within the EU, denoted *R*, and the single-element subset *RoW*, the rest of the world. We will need a partition *R* into countries; these national entities will be indexed by *Cnt*.

- Sectors of activity: subscript *s* or *s*'

AllS defines the set of all sectors of activity. Currently, these are:

AllS = { *Agriculture, Manufacturing + Construction, Trade + Transport, Business Services, Non-market services, R&D* }.

S defines sectors specific to regions as opposed to countries, all except R&D.

S = { *Agriculture, Manufacturing + Construction, Trade + Transport, Business Services, Non-market services* }.

$AllS^{CP}$ includes all perfectly competitive sectors.

$AllS^{CP}$ = { *Agriculture, Non-market services* }.

$AllS^{CI}$ includes all imperfectly perfectly competitive sectors.

$AllS^{CI}$ = { *Manufacturing + Construction, Trade + Transport, Business Services, R&D* }.

S^{CP} includes all perfectly competitive sectors operating at regional level.

S^{CP} = { *Agriculture, Non-market services* }

S^{CI} includes all imperfectly competitive sectors operating at regional level.

S^{CI} = { *Manufacturing + Construction, Trade + Transport, Business Services* }.

- Production factors: subscript *f*

AllF defines the set of all factors introduced in the model:

AllF= { *Lab-L, Lab-M, Lab-H, Lab-H-RnD, Lab-H-NonRnD, KapHou, KapGov, KapEur* }

where

Lab-L, Lab-M, Lab-H labels respectively low-, medium- and high- skill labour;

Lab-H-RnD, Lab-H-NonRnD labels high-skill labour specific to R&D vs. non-R&D specific;

KapHou, KapGov labels capital owned by households as opposed to public capital;

KapEur labels capital supplied by an aggregate EU agent (to be defined later).

AllFEndo refers to all households' factor endowments:

AllFEndo= { *Lab-L, Lab-M, Lab-H, KapHou* }

AllLEndo refers to all households' labour endowments:

AllLEndo= { *Lab-L, Lab-M, Lab-H* }

AllFUsed defines the set of all factors used in production:

AllFUsed= { *Lab-L, Lab-M, Lab-H-RnD, Lab-H-NonRnD, KapGov, KapEur* }.

AllLUsed defines the set of all labour types used in production:

AllLUsed= { *Lab-L, Lab-M, Lab-H-RnD, Lab-H-NonRnD* }.

LUsed-H distinguishes between region specific high skill labour (non-RnD) vs. national (RnD):

LUsed-H= { *Lab-H-RnD, Lab-H-NonRnD* }.

LUsed-NonH defines the subset of labour service types used by firms operating regionally (i.e. non-R&D firms):

LUsed-NonH = { *Lab-L, Lab-M, Lab-H-NonRnD* }.

AllKUsed defines the set of all capital types used by firms:

AllKUsed= {*KapGov, KapEur* }.

8.2 LIST OF RHOMOLO-V2 VARIABLES AND PARAMETERS

8.2.1 HOUSEHOLDS

Variable	*Description* (*for each region r*)	*Source*
$p_{r,f}^{Fac}$	Price of $F_{r,f}^{SupHou}$	Normalised
$F_{r,f}^{SupHou}$	Factor f, household (real)	SAM
Inc_r^{Hou}	Income of household (value)	SAM
$Tx_r^{Inc^{Hou}}$	Taxes paid on Inc_r^{Hou} (value)	SAM
Sav_r^{Hou}	Savings of household (value)	SAM
Con_r^{Hou}	Aggregate consumption of household (real)	SAM
$p_r^{Con^{Hou}}$	Price of Con_r^{Hou}	Normalised
$ConS_{r,s}^{Hou}$	Consumption of good *s* by household (real)	SAM
$Transf_r^{Hou \to ROW}$	Transfers from household to rest of the world	SAM

Parameter	*Description*	*Source*
$\alpha_{r,f}^{FacSupLab-H}$	CET share parameter in $F_{r,Lab-H}^{SupHou}$	Calibrated
$\sigma_r^{FacSupLab-H}$	Transformation elasticity in $F_{r,Lab-H}^{SupHou}$	Literature [1]
$TxR_r^{Inc^{Hou}}$	Tax rate on household income	Calibrated
$SavR_r^{Hou}$	Savings rate of household	Calibrated
$\alpha_{r,s}^{ConS^{Hou}}$	CES share parameter in $ConS_{r,s}^{Hou}$	Calibrated
$\sigma_r^{Con^{Hou}}$	Substitution elasticity in Con_r^{Hou}	Literature [1.2]

8.2.2 FIRMS

Variable	*Description*	*Source*
$p_{r,s,r'}^{Exp}$	Price of $Exp_{r,s,r'}$	Normalised
$Lerner_{r,s,r'}$	Lerner index in *r'* of (*r*,*s*)-firm	Calibrated
$MSh_{r,s,r'}$	Market share in *r'* of (*r*,*s*)-firm	Calibrated
$p_{r,s}^{Z}$	Average sales price of $Z_{r,s}$	Normalised
$Av_{r,s}^{Cost}$	Average production cost	Normalised
$Prof_{r,s}$	Profits (value)	Calibrated
$Fx_{r,s}^{Cost}$	Fixed cost of production (real)	Calibrated
$Ma_{r,s}^{Cost}$	Marginal cost of production	Calibrated
$X_{r,s}$	Demand for aggregate intermediate input (real)	SAM
$Q_{r,s}$	Demand for aggregate value added (real)	SAM
$p_{r,s}^{X}$	Price of $X_{r,s}$	Normalised
$XS_{r,s',s}$	Demand for Intermediate good *s'* by (*r*,*s*)-firm (real)	SAM
$TFP_{r,s}$	Total factor productivity index	Normalised
$p_{r,s}^{Q}$	Price of $Q_{r,s}$	Normalised
$Kap_{r,s}^{Dem}$	Demand for aggregate capital factor (real)	SAM
$Lab_{r,s}^{Dem}$	Demand for aggregate labour factor (real)	SAM
$p_{r,s}^{Kap}$	Price of $Kap_{r,s}^{Dem}$	Normalised
$p_{r,s}^{Lab}$	Price of $Lab_{r,s}^{Dem}$	Normalised
$F_{r,f,s}^{Dem}$	Demand of factor *f* by (*r*,*s*)-firm (real)	SAM
$Tx_{r,f,s}^{FDem}$	Taxes paid on $F_{r,f,s}^{Dem}$ (value)	SAM
$Tx_{r,s}^{Z}$	Taxes paid on $Z_{r,s}$ (value)	SAM

Parameter	*Description*	*Source*
$\alpha^{X}_{r,s}$	CES share parameter of $X_{r,s}$	Calibrated
$\alpha^{Q}_{r,s}$	CES share parameter of $Q_{r,s}$	Calibrated
$\sigma^{Z}_{r,s}$	Substitution elasticity of $Z_{r,s}$	Literature [0.2]
$\alpha^{XS}_{r,s\prime,s}$	CES share parameter of $XS_{r,s\prime,s}$	Calibrated
$\sigma^{X}_{r,s}$	Substitution elasticity of $X_{r,s}$	Literature [0.25]
$KnowK^{Ext}_{r,s}$	Knowledge externality parameter in $TFP_{r,s}$	Literature [0.53]
$\alpha^{KapDem}_{r,s}$	CES share parameter of $Kap^{Dem}_{r,s}$	Calibrated
$\alpha^{LabDem}_{r,s}$	CES share parameter of $Lab^{Dem}_{r,s}$	Calibrated
$\sigma^{Q}_{r,s}$	Substitution elasticity of $Q_{r,s}$	Literature [1]
$\alpha^{FDem}_{r,f,s}$	CES share parameter of $F^{Dem}_{r,f,s}$	Calibrated
$TKP_{r,s}$	Total capital productivity index	Normalised
$\sigma^{Kap}_{r,s}$	Substitution elasticity of$Kap^{Dem}_{r,s}$	Literature [2]
$TLP_{r,s}$	Total labour productivity index	Normalised
$\sigma^{Lab}_{r,s}$	Substitution elasticity of$Lab^{Dem}_{r,s}$	Literature [1.5]
$TxR^{FDem}_{r,f,s}$	Tax rates on $F^{Dem}_{r,s,f}$	SAM
$TxR^{Z}_{r,s}$	Tax rates on $Z_{r,s}$	SAM

8.2.3 Investment demand for local goods

Variable	*Description* *(for each region r)*	*Source*
p^{Inv}_{r}	Price of Inv_{r}	Normalised
$InvS_{r,s}$	Demand of good (*r,s*) by investor (real)	SAM

Parameter	Description	Source
$\alpha_{r,s}^{Inv}$	CES share parameter of $InvS_{r,s}$	Calibrated
σ_r^{Inv}	Substitution elasticity of Inv_r	Literature [1.3]

8.2.4 The government

Variable	Description (for each region r)	Source
$F_{r,f}^{supGov}$	Factor f supply by Government (real)	SAM
Inc_r^{Gov}	Income of Government (value)	SAM
Con_r^{Gov}	Aggregate consumption of Government (real)	SAM
$p_r^{Con^{Gov}}$	Price of Con_r^{Gov}	Normalised
$ConS_{r,s}^{Gov}$	Consumption of good *s* by Government (real)	SAM
$Transf_r^{Gov\rightarrow Hou}$	Transfers from Government to household (value)	SAM
Sav_r^{Gov}	Savings of Government (value, constant)	SAM
Parameter	*Description*	*Source*
$\alpha_{r,s}^{ConS^{Gov}}$	CES share parameter of $ConS_{r,s}^{Gov}$	Calibrated
$\sigma_r^{Con^{Gov}}$	Substitution elasticity of Con_r^{Gov}	Literature [0.3]

8.2.5 Price, level and composition of the demand for market goods

Variable	Description	Source
$Arm_{r,s}$	Demand for (Armington/Dixit-Stiglitz) composite good *s* (real)	SAM
$StVar_{r,s}$	Stock variations (constant)	SAM
$p_{r,s}^{Arm}$	Price of $Arm_{r,s}$	Normalised
$Exp_{r',s,r}$	Exports from (*r',s*)- firm to *r* (real)	SAM

Parameter	*Description*	*Source*
$\alpha_{r\prime,s,r}^{Exp}$	CES share parameter of $Exp_{r\prime,s,r}$	Calibrated
$\sigma_{r,s}^{Arm}$	Substitution elasticity of $Arm_{r,s}$	Literature [6.0]
$TrCost_{r\prime,r}$	Iceberg transport cost rate from *r'* to *r*	Calibrated

8.2.6 The European capital market

Variable	*Description* *(for each good s)*	*Source*
Sav_r	Aggregate savings of *r* (value)	SAM
$Sav_r^{EU\rightarrow r}$	Flow savings from *EU* zone to *r* (value)	SAM
$Sav_r^{RoW\rightarrow r}$	Flow savings from *RoW* to *r* (value)	SAM
$EuroInc^{Inv}$	Aggregate EU investment resources (value)	SAM
$EuroInv$	Aggregate EU investment (real)	SAM
$p^{EuroInv}$	Price of $EuroInv$	Normalised
Inv_r	Aggregate EU investment expenditure on region *r* good	SAM
$EuroKap$	Aggregate EU capital stock	SAM
$p^{EuroKap}$	Price of $EuroKap$	Normalised

Parameter	*Description*	*Source*
$\alpha_r^{EuroInv}$	CES share parameter of Inv_r	Calibrated
$\sigma^{EuroInv}$	Substitution elasticity of $EuroInv$	Literature [3]
$\sigma^{EuroKap}$	Elasticity of transformation of EU capital between regions	Literature [3]

8.2.7 A NATIONAL SECTOR OF ACTIVITY: THE SECTOR FOR R&D AND INNOVATION

Variable	*Description*	*Source*
$p^{Z}_{Cnt,RnD}$	Price of $Z_{Cnt,RnD}$	Normalised
$Z_{Cnt,RnD}$	National R&D Output (real)	SAM
$Ma^{Cost}_{Cnt,RnD}$	Marginal cost of R&D	Normalised
$Prof_{Cnt,RnD}$	National profits in R&D	SAM
$KnowK_{Cnt}$	National knowledge capital (real)	SAM
Parameter	*Description*	*Source*
$\mathrm{Fx}^{\mathrm{Cost}}_{\mathrm{Cnt,RnD}}$	Fixed cost of production in National R&D (real)	Calibrated
$TFP_{Cnt,Rnd}$	Total factor productivity index in National R&D	Calibrated
$\sigma^{\mathrm{Arm}}_{\mathrm{Cnt,RnD}}$	Substitution between R&D varieties	Literature [3]

8.2.8 EQUILIBRIUM CONDITIONS

Variable	*Description*	*Source*
$p^{Fac}_{r,f}$	Price of factor f	Normalised
$UnEmpRte_{f}$	Unemployment rate, factor f	Data
$Z_{r,s}$	Total sales by (*r,s*)-firm (real)	SAM
$N_{r,s}$	Number of (*r,s*)-firms	Data
Parameter	*Description*	*Source*
$\varepsilon^{wagecurve}_{r}$	(Absolute value of) wage curve elasticity	Literature [0.1]

8.2.9 THE REST OF THE WORLD

Variable	*Description*	*Source*
$p_{RoW,s,r}^{Exp}$	Price of *ROW* goods (numeraire)	Normalised
$Sav_r^{ROW\rightarrow r}$	Flow savings from *ROW* to *r* (value)	SAM

8.2.10 DYNAMICS

Parameter	*Description*	*Source*
δ_r	Depreciation rate (constant)	Calibrated
κ	Factor converting stock into a yearly flow of capital services	Calibrated (constant)

8.3 EQUATIONS OF RHOMOLO-V2 AS IMPLEMENTED IN THE GAMS CODE

8.3.1 HOUSEHOLDS

$(\forall \boldsymbol{r})$

$(p_{r,Lab-H}^{Fac})$ $$\left[p_{r,Lab-H}^{Fac}\right]^{1+\sigma_r^{FacSupLab-H}} = \sum_{f\in LUsed-H} \alpha_{r,f}^{FacSupLab-H} \left[p_{r,f}^{Fac}\right]^{1+\sigma_r^{FacSupLab-H}} \quad (1)$$

$(F_{r,f}^{supHou})$ $$F_{r,f}^{supHou} = \alpha_{r,f}^{FacSupLab-H} \left[\frac{p_{r,f}^{Fac}}{p_{r,Lab-H}^{Fac}}\right]^{\sigma_r^{FacSupLab-H}} \cdot \left[1 - UnEmpRte_{r,Lab-H}\right] F_{r,Lab-H}^{supHou}, \quad (2)$$

$f \in LUsed - H$

$(p_{r,KapHou}^{Fac})$ $$p_{r,KapHou}^{Fac} = p^{EuroKap} \quad (3)$$

(Inc_r^{Hou}) $$Inc_r^{Hou} = \sum_{f\in AllFEndo} p_{r,f}^{Fac}\left(1 - UnEmpRte_{r,f}\right)F_{r,f}^{SupHou} + Transf_r^{Gov\rightarrow Hou} + \sum_{s\in AllS} N_{rs}Prof_{r,s} \quad (4)$$

(Tx_r^{IncHou}) $$Tx_r^{IncHou} = TxR_r^{IncHou} Inc_r^{Hou}, \quad (5)$$

$$(Sav_r^{Hou}) \qquad Sav_r^{Hou} = SavR_r^{Hou}\left(Inc_r^{Hou} - Tx_r^{Inc^{Hou}} - p_r^{Con^{Hou}} Transf_r^{Hou \to RoW}\right) \qquad (6)$$

$$(Con_r^{Hou}) \qquad p_r^{Con^{Hou}} Con_r^{Hou} = (1 - SavR_r^{Hou})\,(Inc_r^{Hou} - Tx_r^{Inc^{Hou}} - p_r^{Con^{Hou}} Transf_r^{Hou \to RoW}) \qquad (7)$$

$$(p_r^{Con^{Hou}}) \qquad \left[p_r^{Con^{Hou}}\right]^{1-\sigma_r^{Con^{Hou}}} = \sum_{s \in AllS} \alpha_{r,s}^{ConS^{Hou}} \left[p_{r,s}^{Arm}\right]^{1-\sigma_r^{Con^{Hou}}} \qquad (8)$$

$$(ConS_{r,s}^{Hou}) \qquad ConS_{r,s}^{Hou} = \alpha_{r,s}^{ConS^{Hou}} \left(\frac{p_r^{Con^{Hou}}}{p_{r,s}^{Arm}}\right)^{\sigma_r^{Con^{Hou}}} Con_r^{Hou} \qquad (9)$$

8.3.2 Firms

($\forall \boldsymbol{r}, \forall \boldsymbol{s}$; all variables defined for the individual firm)

$$(p_{r,s,r'}^{Exp}) \qquad \frac{p_{r,s,r'}^{Exp} - Ma_{r,s}^{Cost}}{p_{r,s,r'}^{Exp}} = Lerner_{r,s,r'} \quad , \quad r' \in AllR \qquad (10)$$

$$(Lerner_{r,s,r'}) \qquad Lerner_{r,s,r'} = \frac{1}{\sigma_{r',s}^{Arm} - \left(\sigma_{r',s}^{Arm} - 1\right) MSh_{r,s,r'}} \quad , \quad r' \in AllR \qquad (11)$$

$$(Lerner_{r,s,r'}) \qquad Lerner_{r,s,r'} = \frac{1}{\sigma_{r',s}^{Arm}} - \left(\frac{1}{\sigma_{r',s}^{Arm}} - 1\right) MSh_{r,s,r'} \quad , \quad r' \in AllR \qquad (12)$$

$$(MSh_{r,s,r'}) \qquad MSh_{r,s,r'} = \frac{\left(1 + TxR_{r,s}^{Z}\right) p_{r,s,r'}^{Exp} Exp_{r,s,r'}}{p_{r',s}^{Arm} Arm_{r',s}} \quad , \quad r' \in AllR \qquad (13)$$

$$(p_{r,s}^{Z}) \qquad p_{r,s}^{Z} = \frac{\sum_{r' \in AllR} p_{r,s,r'}^{Exp} Exp_{r,s,r'}}{\sum_{r' \in AllR} Exp_{r,s,r'}} \qquad (14)$$

$$(Av_{r,s}^{Cost}) \qquad Av_{r,s}^{Cost} Z_{r,s} = Ma_{r,s}^{Cost}\left[Z_{r,s} + Fx_{r,s}^{Cost}\right] \qquad (15)$$

$$(Prof_{r,s}) \qquad Prof_{r,s} = \left[p_{r,s}^{Z} - Av_{r,s}^{Cost}\right] Z_{r,s} \qquad (16)$$

$$(Ma_{r,s}^{Cost}) \qquad \left[Ma_{r,s}^{Cost}\right]^{1-\sigma_{r,s}^{Z}} = \alpha_{r,s}^{X}\left[p_{r,s}^{X}\right]^{1-\sigma_{r,s}^{Z}} + \alpha_{r,s}^{Q}\left[p_{r,s}^{Q}\right]^{1-\sigma_{r,s}^{Z}} \qquad (17)$$

$$(X_{r,s}) \qquad X_{r,s} = \alpha_{r,s}^{X}\left[\frac{MA_{r,s}^{Cost}}{p_{r,s}^{X}}\right]^{\sigma_{r,s}^{Z}} \left[Z_{r,s} + Fx_{r,s}^{Cost}\right] \qquad (18)$$

$(Q_{r,s})$	$Q_{r,s} = \alpha_{r,s}^{Q}\left[\frac{MA_{r,s}^{Cost}}{p_{r,s}^{Q}}\right]^{\sigma_{r,s}^{Z}}\left[Z_{r,s} + Fx_{r,s}^{Cost}\right]$	(19)
$(p_{r,s}^{X})$	$\left[p_{r,s}^{X}\right]^{1-\sigma_{r,s}^{X}} = \sum_{s\prime\in AllS} \alpha_{r,s\prime,s}^{XS}\left[p_{r,s\prime}^{Arm}\right]^{1-\sigma_{r,s}^{X}}$	(20)
$(XS_{r,s\prime,s})$	$XS_{r,s\prime,s} = \alpha_{r,s\prime,s}^{XS}\left(\frac{p_{r,s}^{X}}{p_{r,s\prime}^{Arm}}\right)^{\sigma_{r,s}^{X}} X_{r,s} \quad s' \in AllS$	(21)
$(TFP_{r,s})$	$TFP_{r,s} = TFP0_{r,s}\left[\frac{KnowK_{Cnt}}{KnowK0_{Cnt}}\right]^{KnowK_{r,s}^{Ext}} \quad , \ r \in Cnt$	(22)
$(p_{r,s}^{Q})$	$\left[p_{r,s}^{Q}\right]^{1-\sigma_{r,s}^{Q}} = TFP_{r,s}{}^{\sigma_{r,s}^{Q}-1}\left[\alpha_{r,s}^{KapDem}\left[p_{r,s}^{Kap}\right]^{1-\sigma_{r,s}^{Q}} + \alpha_{r,s}^{LabDem}\left[p_{r,s}^{Lab}\right]^{1-\sigma_{r,s}^{Q}}\right]$	(23)
$(Kap_{r,s}^{Dem})$	$Kap_{r,s}^{Dem} = TFP_{r,s}{}^{\sigma_{r,s}^{Q}-1}\alpha_{r,s}^{KapDem}\left[\frac{p_{r,s}^{Q}}{p_{r,s}^{Kap}}\right]^{\sigma_{r,s}^{Q}} Q_{r,s}$	(24)
$(Lab_{r,s}^{Dem})$	$Lab_{r,s}^{Dem} = TFP_{r,s}{}^{\sigma_{r,s}^{Q}-1}\alpha_{r,s}^{LabDem}\left[\frac{p_{r,s}^{Q}}{p_{r,s}^{Lab}}\right]^{\sigma_{r,s}^{Q}} Q_{r,s}$	(25)
$(p_{r,s}^{Kap})$	$\left[p_{r,s}^{Kap}\right]^{1-\sigma_{r,s}^{Kap}} = TKP_{r,s}{}^{\sigma_{r,s}^{Kap}-1} \sum_{f\in AllKUsed} \alpha_{r,s,f}^{FDem}\cdot\left[\left(1 + TxR_{r,s,f}^{FDem}\right)p_{r,f}^{Fac}\right]^{1-\sigma_{r,s}^{Kap}}$	(26)
$(F_{r,s,f}^{Dem})$	$F_{r,s,f}^{Dem} = TKP_{r,s}{}^{\sigma_{r,s}^{Kap}-1}\alpha_{r,s,f}^{FDem}\left[\frac{p_{r,s}^{Kap}}{\left(1 + TxR_{r,s,f}^{FDem}\right)p_{r,f}^{Fac}}\right]^{\sigma_{r,s}^{Kap}} Kap_{r,s}^{Dem} \ , f \in AllKUsed$	(27)
$(p_{r,s}^{Lab})$	$\left[p_{r,s}^{Lab}\right]^{1-\sigma_{r,s}^{Lab}} = TKP_{r,s}{}^{\sigma_{r,s}^{Lab}-1} \sum_{f\in LUsed-NonH} \alpha_{r,s,f}^{FDem}\cdot\left[\left(1 + TxR_{r,s,f}^{FDem}\right)p_{r,f}^{Fac}\right]^{1-\sigma_{r,s}^{Lab}}$	(28)
$(F_{r,s,f}^{Dem})$	$F_{r,s,f}^{Dem} = TKP_{r,s}{}^{\sigma_{r,s}^{Lab}-1}\alpha_{r,s,f}^{FDem}\left[\frac{p_{r,s}^{Lab}}{\left(1 + TxR_{r,s,f}^{FDem}\right)p_{r,f}^{Fac}}\right]^{\sigma_{r,s}^{Lab}} Lab_{r,s}^{Dem} \quad , \quad f \in LUsed - NonH$	(29)
$(Tx_{r,s,f}^{FDem})$	$Tx_{r,s,f}^{FDem} = TxR_{r,s,f}^{FDem}\, p_{r,f}^{Fac}\, F_{r,s,f}^{Dem} \quad , \ f = AllFUsed$	(30)
$(Tx_{r,s}^{Z})$	$Tx_{r,s}^{Z} = TxR_{r,s}^{Z}\, p_{r,s}^{Z}\, Z_{r,s} \quad , \ s \in S$	(31)

8.3.3 Investment demand for local goods

$\forall \boldsymbol{r}$

(p_r^{Inv}) $$[p_r^{Inv}]^{1-\sigma^{Inv}} = \sum_{s \in AllS} \alpha_{r,s}^{Inv} [p_{r,s}^{Arm}]^{1-\sigma^{Inv}} \quad (32)$$

$(InvS_{r,s})$ $$InvS_{r,s} = \alpha_{r,s}^{Inv} \left[\frac{p_r^{Inv}}{p_{r,s}^{Arm}}\right]^{\sigma^{Inv}} Inv_r \quad , \quad s \in AllS \quad (33)$$

8.3.4 The government

$\forall \boldsymbol{r}$

(Inc_r^{Gov}) $$Inc_r^{Gov} = Tx_r^{Inc^{Hou}} + \sum_{s \in AllS} N_{r,s} Tx_{r,s}^{Z} + \sum_{s \in AllS, f \in AllFUsed} N_{rs} Tx_{r,f,s}^{F^{Dem}} + p_{r,KapGov}^{Fac} F_{r,KapGov}^{SupGov} \quad (34)$$

$(P_r^{Con^{Gov}})$ $$\left[P_r^{Con^{Gov}}\right]^{1-\sigma_r^{Con^{Gov}}} = \sum_{s \in AllS} \alpha_{r,s}^{Con^{Gov}} \left[p_{r,s}^{Arm}\right]^{1-\sigma_r^{Con^{Gov}}} \quad (35)$$

$(ConS_{r,s}^{Gov})$ $$ConS_{r,s}^{Gov} = \alpha_{r,s}^{Con^{Gov}} \left[\frac{p_r^{Con^{Gov}}}{p_{r,s}^{Arm}}\right]^{\sigma_r^{Con^{Gov}}} Con_r^{Gov} \quad , \quad s \in AllS \quad (36)$$

$(Transf_r^{Gov \to I}$ $$Transf_r^{Gov \to Hou} = p_r^{Con^{Gov}} Transf0_r^{Gov \to Hou} \quad (37)$$

(Sav_r^{Gov}) $$Sav_r^{Gov} = Inc_r^{Gov} - p_r^{Con^{Gov}} Con_r^{Gov} - Transf_r^{Gov \to Hou} \quad (38)$$

8.3.5 Price, level and composition of the demand for market goods

$\forall \boldsymbol{r}$

$(Arm_{r,s})$ $$Arm_{r,s} = \sum_{s' \in AllS} N_{r,s'}\ XS_{r,s,s'} + ConS_{r,s}^{Hou} + ConS_{r,s}^{Gov} + InvS_{r,s} \quad , \quad s \in AllS \quad (39)$$

$(p_{r,s}^{Arm})$ $$\left[p_{r,s}^{Arm}\right]^{1-\sigma_s^{Arm}} = \sum_{r' \in AllR} N_{r',s} \alpha_{r',s,r}^{Exp} \left[(1 + TrCost_{r',s,r}) \cdot (1 + TxR_{r',s}^{Z}) p_{r',s,r}^{Exp}\right]^{1-\sigma_s^{Arm}}, \qquad r \in AllR\ , s \in S \quad (40)$$

$(Exp_{r',s,r})$ $$\frac{Exp_{r',s,r}}{1 + TrCost_{r',s,r}} = \alpha_{r',s,r}^{Exp} \left[\frac{p_{r,s}^{Arm}}{(1 + TrCost_{r',s,r})(1 + TxR_{r',s}^{Z}) p_{r',s,r}^{Exp}}\right]^{\sigma^{Arm}} Arm_{r,s}\ , r, r' \in AllR, \ \ s \in AllS \quad (41)$$

$(P_{r,RnD}^{Arm})$ $$p_{r,RnD}^{Arm} = p_{Cnt,RnD}^{Z}. \quad (42)$$

8.3.6 The European capital market

(Sav_r)	$Sav_r = Sav_r^{Hou} + Sav_r^{Gov} + Sav_r^{EU\to r} + Sav_r^{ROW\to r} \qquad ,r \in R$	(43)
$(EuroInc^{Inv})$	$EuroInc^{Inv} = \sum_{r\in R} Sav_r$	(44)
$(EuroInv)$	$p^{EuroInv} EuroInv = EuroInc^{Inv}$	(45)
$(p^{EuroInv})$	$[p^{EuroInv}]^{1-\sigma^{EuroInv}} = \sum_{r\in R} \alpha_r^{EuroInv} [p_r^{Inv}]^{1-\sigma^{EuroInv}}$	(46)
(Inv_r)	$Inv_r = \alpha_r^{EuroInv} \left[\frac{p^{EuroInv}}{p_r^{Inv}}\right]^{\sigma^{EuroInv}} EuroInv \qquad ,r \in R$	(47)
$(EuroKap)$	$EuroKap = \sum_{r\in R} F_{r,KapHou}^{SupHou}$	(48)
$(p^{EuroKap})$	$[p^{EuroKap}]^{1+\sigma^{EuroKap}} = \sum_{r\in R} \alpha_r^{SupKapEur} \left[p_{r,KapEur}^{Fac}\right]^{1+\sigma^{EurKap}}$	(49)
$(F_{r,KapEur}^{SupHou})$	$F_{r,KapEur}^{SupHou} = \alpha_r^{SupKapEur} \left[\frac{p_{r,KapEur}^{Fac}}{p^{EuroKap}}\right]^{\sigma^{EuroKap}} EuroKap \qquad , r \in R$	(50)

8.3.7 A national sector of activity: the sector for R&D and innovation

$\forall \boldsymbol{Cnt}$

$(p_{Cnt,RnD}^{Z})$	$p_{Cnt,RnD}^{Z} = Ma_{Cnt,RnD}^{Cost} \left[\frac{\sigma_{Cnt,RnD}^{Arm}}{\sigma_{Cnt,RnD}^{Arm} - 1}\right]$	(51)
$(Z_{Cnt,RnD})$	$Z_{Cnt,RnD} = \sum_{r\in Cnt} Arm_{r,RnD}$	(52)
$(F_{r,Lab\_H\_RnD}^{Dem})$	$Ma_{Cnt,RnD}^{Cost}\left[Z_{Cnt,RnD} + Fx_{Cnt,Rnd}^{Cost}\right] = \sum_{r\in Cnt} p_{r,Lab\_H\_RnD}^{Fac} F_{r,Lab\_H\_RnD}^{Dem}$	(53)
$(p_{r,Lab-H-RnD}^{Fac})$	$p_{r,Lab-H-RnD}^{Fac} = TFP_{Cnt,RnD} Ma_{Cnt,RnD}^{Cost} \qquad , r \in Cnt$	(54)
$(Prof_{Cnt,RnD})$	$Prof_{Cnt,RnD} = p_{Cnt,RnD}^{Z} Z_{Cnt,RnD} - Ma_{Cnt,RnD}^{Cost}\left[Z_{Cnt,RnD} + Fx_{Cnt,Rnd}^{Cost}\right]$	(55)
$(Prof_{r,RnD})$	$Prof_{r,RnD} = Prof_{Cnt,RnD} \frac{F_{r,Lab-H-RnD}^{dem}}{\sum_{r\in Cnt} F_{r,Lab-H-RnD}^{dem}}$	(56)
$(N_{r,RnD})$	$N_{r,RnD} = N_{Cnt,RnD} \qquad , r \in Cnt$	(57)
$(KnowK_{Cnt})$	$KnowK_{Cnt} = N_{Cnt,RnD} Z_{Cnt,RnD}$	(58)

8.3.8 EQUILIBRIUM CONDITIONS

$\forall \boldsymbol{r}$

$$(p_{r,f}^{Fac}) \qquad [1 - UnEmpRte_f]F_{r,f}^{SupHou} + F_{r,f}^{SupGov} = \sum_{s\in AllS} N_{r,s}F_{r,s,f}^{Dem} \ \ , \ r \in R \ , \ f \in AllFUsed \tag{59}$$

$$(UnEmpRte_f) \qquad \frac{p_{r,f}^{Fac}}{p_r^{Con^{Hou}}} = -\,\epsilon^{wagecurve}\,\frac{UnEmpRte_{r,f}}{UnEmpRte0_{r,f}} \quad , \qquad r \in R\,, \quad f \in AllLEndo \tag{60}$$

$$(Z_{r,s}) \qquad Z_{r,s} = \sum_{r\prime \in AllR} Exp_{r,s,r\prime} \quad , \qquad r \in R\,, \quad s \in S \tag{61}$$

$$(N_{r,s}) \qquad Av_{r,s}^{Cost} = p_{r,s}^{Z} \quad , \ s \in SCI \tag{62}$$

8.3.9 THE REST OF THE WORLD

$$\begin{aligned}\sum_{r\in R}\left(p_{\mathrm{r}}^{Con^{Hou}} Transf_r^{Hou\to RoW} + \sum_{s\in AllS} p_{RoW,s,r}^{Exp} Exp_{RoW,s,r}\right) &= \\ = \sum_{r\in R}\left(\sum_{s\in AllS}\left((1 + TxR_{\mathrm{r,s}}^{Z})p_{r,s,RoW}^{Exp} N_{r,s} Exp_{r,s,RoW}\right) + Sav_r^{RoW\to R}\right)&\end{aligned} \tag{63}$$

8.3.10 DYNAMICS

Upgrading of production factors

$$p_t^{EuroInv} F_{t+1,r,f}^{supHou} = (1-\delta)p_{t-1}^{EuroInv} F_{t,r,f}^{supHou} + \kappa Sav_{t,r} \qquad r \in R, \qquad f = KapHou \tag{64}$$

Dynamic wage equation

$$\begin{aligned} log\left(\frac{p_{t,r,f}^{Fac}}{p_{t,r,f}^{Hou}}\right) &= a_r + \alpha_r\left(\frac{p_{t-1,r,f}^{Fac}}{p_{t-1,r,f}^{Hou}}\right) - \varepsilon_r \log(UnEmpRte_t) + \gamma_r\big(\log(p_{t,r}) - \log(p_{t-1,r})\big) \\ &\quad - \lambda_r\left(log\left(\frac{p_{t-1,r,f}^{Fac}}{p_{t-1,r,f}^{Hou}}\right) - \log(\tau_t)\right) - \theta_r(\log(UnEmpRte_t) - \log(UnEmpRte_{t-1}))\ , \\ &\quad f \ \in AllLEndo \end{aligned} \tag{65}$$

8.4 RHOMOLO-v2 SECTOR AND REGION CLASSIFICATION

8.4.1 THE SECTORAL CLASSIFICATION

The model covers six sectors of economic activity, including R&D as a separate sector. The classification used in RHOMOLO is the result of the aggregation of the 59 productive sectors represented in the Social Accounting Matrices at national level.

The main data source for the Input-Output framework of the Social Accounting Matrices is the World Input-Output Database (WIOD). In WIOD the information is disposable for 35 industries (ISIC[44] Rev. 3 or NACE[45] Rev. 1) and 59 products/commodities (CPA[46] 1996).

Table 3 displays the six macro-sectors represented in RHOMOLO and the corresponding 59 products/sectors included according to NACE Rev. 1.

Table 3. Macro-sectors in RHOMOLO-v2 according to NACE Rev. 1

Code	*Sector description*
AB	Agriculture, hunting, forestry + Fishing
A01	Agriculture, hunting and related service activities
A02	Forestry, logging and related service activities
B	Fishing
CDEF	Mining and quarrying + Manufacturing + Electricity, gas and water supply + Construction
CA10	Mining of coal and lignite; extraction of peat
CA11	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction, excluding surveying
CA12	Mining of uranium and thorium ores
CB13	Mining of metal ores
CB14	Other mining and quarrying
DA15	Manufacture of food products and beverages
DA16	Manufacture of tobacco products
DB17	Manufacture of textiles
DB18	Manufacture of wearing apparel; dressing and dyeing of fur
DC	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
DD	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
DE21	Manufacture of pulp, paper and paper products
DE22	Publishing, printing and reproduction of recorded media
DF	Manufacture of coke, refined petroleum products and nuclear fuel

[44] International standard industrial classification of all economic activities.

[45] Statistical classification of economic activities in the European Community.

[46] Statistical classification of products by activity in the European Economic Community.

Code	Sector description
DG	Manufacture of chemicals and chemical products
DH	Manufacture of rubber and plastic products
DI	Manufacture of other non-metallic mineral products
DJ27	Manufacture of basic metals
DJ28	Manufacture of fabricated metal products, except machinery and equipment
DK	Manufacture of machinery and equipment n.e.c.
DL30	Manufacture of office machinery and computers
DL31	Manufacture of electrical machinery and apparatus n.e.c.
DL32	Manufacture of radio, television and communication equipment and apparatus
DL33	Manufacture of medical, precision and optical instruments, watches and clocks
DM34	Manufacture of motor vehicles, trailers and semi-trailers
DM35	Manufacture of other transport equipment
DN36	Manufacture of furniture; manufacturing n.e.c.
DN37	Recycling
E40	Electricity, gas, steam and hot water supply
E41	Collection, purification and distribution of water
F	Construction
GHI	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods + Hotels and restaurants + Transport, storage and communication
G50	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel
G51	Wholesale trade and commission trade, except of motor vehicles and motorcycles
G52	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods
H	Hotels and restaurants
I60	Land transport; transport via pipelines
I61	Water transport
I62	Air transport
I63	Supporting and auxiliary transport activities; activities of travel agencies
I64	Post and telecommunications
JK	Financial intermediation + Real state, renting and business activities
J65	Financial intermediation, except insurance and pension funding
J66	Insurance and pension funding, except compulsory social security
J67	Activities auxiliary to financial intermediation
K70	Real estate activities
K71	Renting of machinery and equipment without operator and of personal and household goods
K72	Computer and related activities
K74	Other business activities
LMNOP	Non-market services
L	Public administration and defence; compulsory social security
M	Education
N	Health and social work
O90	Sewage and refuse disposal, sanitation and similar activities

Code	Sector description
091	Activities of membership organisations n.e.c.
092	Recreational, cultural and sporting activities
093	Other service activities
P	Activities of households
R&D(K73)	Research and development

8.4.2 THE NOMENCLATURE OF TERRITORIAL UNITS FOR STATISTICS

The NUTS classification (Nomenclature of territorial units for statistics)[47] is a hierarchical system for dividing up the economic territory of the EU for the purpose of:

- The collection, development and harmonisation of EU regional statistics.
- Socio-economic analyses of the regions.
  - NUTS 1: major socio-economic regions
  - NUTS 2: basic regions for the application of regional policies
  - NUTS 3: small regions for specific diagnoses
- Framing of EU regional policies.

The beneficiaries of the European Union Cohesion Policy are the regions classified at NUTS-2 level. The NUTS classification has been enlarged and amended in several occasions. During the periods 2007-2013 and 2014-2020 at least four different versions of the NUTS classification have been/are in force alternatively. The first version, NUTS 2003, entered into force in July 2003 and was valid[48] until 31st December 2007; it included the enlargements of the EU in 2004 and 2007. The classification has been later amended three times by: the NUTS 2006, valid from 1st January 2008 to 31st December 2011; the NUTS 2010, valid until 31st December 2014 and including Croatia; and the NUTS 2013, the current classification valid from 1st January 2015 onwards.

The version implemented in RHOMOLO is the NUTS 2006. This means that the regions that have later split, merged or shifted boundaries are reflected in the database and simulations as they existed under the NUTS 2006 classification. Table 4 lists the codes and names of the 267 NUTS-2 regions according to the NUTS 2006 classification.

Table 4 lists the changes introduced between NUTS 2006 to NUTS 2010 at NUTS-2 level. Due to boundary shifts, the NUTS 2006 version cannot be reproduced from NUTS 2010 in some regions of DE, IT and UK even if NUTS-3 level data were available. A limited number of region names changed or were corrected in several countries, but this does not affect the composition of those regions. Also, the NUTS 2010 includes the two regions of Croatia.

[47] More detailed information is available at http://ec.europa.eu/eurostat/web/nuts/overview

[48] The validity does not refer to the reference year of the data, but to the dates during which the data transmission to Eurostat was permitted using this version of the classification.

Table 6 indicates these changes introduced between NUTS 2010 to NUTS 2013 at NUTS-2 level.

A further NUTS change is applicable as of 1 January 2016. This change concerns only Portugal that requested an extra NUTS amendment due to the substantial reorganisation at the NUTS-3 level. Except for a code change, there will be no other NUTS-2 changes in Portugal.

Table 4. NUTS-2 Regions in RHOMOLO-v2 according to NUTS 2006 classification

Code	*Name*
BE10	Brussels Hoofdstedelijk Gewest
BE21	Prov. Antwerpen
BE22	Prov. Limburg (BE)
BE23	Prov. Oost-Vlaanderen
BE24	Prov. Vlaams-Brabant
BE25	Prov. West-Vlaanderen
BE31	Prov. Brabant Wallon
BE32	Prov. Hainaut
BE33	Prov. Liège
BE34	Prov. Luxembourg (BE)
BE35	Prov. Namur
BG31	Северозападен
BG32	Северен централен
BG33	Североизточен
BG34	Югоизточен
BG41	Югозападен
BG42	Южен централен
CZ01	Praha
CZ02	Střední Čechy
CZ03	Jihozápad
CZ04	Severozápad
CZ05	Severovýchod
CZ06	Jihovýchod
CZ07	Střední Morava
CZ08	Moravskoslezsko
DK01	Hovedstaden
DK02	Sjælland
DK03	Syddanmark
DK04	Midtjylland
DK05	Nordjylland
DE11	Stuttgart
DE12	Karlsruhe
DE13	Freiburg
DE14	Tübingen
DE21	Oberbayern
DE22	Niederbayern
ITD5	Emilia-Romagna
ITE1	Toscana
ITE2	Umbria
ITE3	Marche
ITE4	Lazio
ITF1	Abruzzo
ITF2	Molise
ITF3	Campania
ITF4	Puglia
ITF5	Basilicata
ITF6	Calabria
ITG1	Sicilia
ITG2	Sardegna
CY00	Κύπρος
LV00	Latvija
LT00	Lietuva
LU00	Luxembourg
HU10	Közép-Magyarország
HU21	Közép-Dunántúl
HU22	Nyugat-Dunántúl
HU23	Dél-Dunántúl
HU31	Észak-Magyarország
HU32	Észak-Alföld
HU33	Dél-Alföld
MT00	Malta
NL11	Groningen
NL12	Friesland (NL)
NL13	Drenthe
NL21	Overijssel
NL22	Gelderland
NL23	Flevoland
NL31	Utrecht
NL32	Noord-Holland
NL33	Zuid-Holland
NL34	Zeeland
NL41	Noord-Brabant

Code	*Name*
DE23	Oberpfalz
DE24	Oberfranken
DE25	Mittelfranken
DE26	Unterfranken
DE27	Schwaben
DE30	Berlin
DE41	Brandenburg - Nordost
DE42	Brandenburg - Südwest
DE50	Bremen
DE60	Hamburg
DE71	Darmstadt
DE72	Gießen
DE73	Kassel
DE80	Mecklenburg-Vorpommern
DE91	Braunschweig
DE92	Hannover
DE93	Lüneburg
DE94	Weser-Ems
DEA1	Düsseldorf
DEA2	Köln
DEA3	Münster
DEA4	Detmold
DEA5	Arnsberg
DEB1	Koblenz
DEB2	Trier
DEB3	Rheinhessen-Pfalz
DEC0	Saarland
DED1	Chemnitz
DED2	Dresden
DED3	Leipzig
DEE0	Sachsen-Anhalt
DEF0	Schleswig-Holstein
DEG0	Thüringen
EE00	Eesti
IE01	Border, Midland and Western
IE02	Southern and Eastern
GR11	Ανατολική Μακεδονία, Θράκη
GR12	Κεντρική Μακεδονία
GR13	Δυτική Μακεδονία
GR14	Θεσσαλία
GR21	Ήπειρος
GR22	Ιόνια Νησιά
GR23	Δυτική Ελλάδα

Code	*Name*
NL42	Limburg (NL)
AT11	Burgenland (AT)
AT12	Niederösterreich
AT13	Wien
AT21	Kärnten
AT22	Steiermark
AT31	Oberösterreich
AT32	Salzburg
AT33	Tirol
AT34	Vorarlberg
PL11	Łódzkie
PL12	Mazowieckie
PL21	Małopolskie
PL22	Śląskie
PL31	Lubelskie
PL32	Podkarpackie
PL33	Świętokrzyskie
PL34	Podlaskie
PL41	Wielkopolskie
PL42	Zachodniopomorskie
PL43	Lubuskie
PL51	Dolnośląskie
PL52	Opolskie
PL61	Kujawsko-Pomorskie
PL62	Warmińsko-Mazurskie
PL63	Pomorskie
PT11	Norte
PT15	Algarve
PT16	Centro (PT)
PT17	Lisboa
PT18	Alentejo
PT20	Região Autónoma dos Açores
PT30	Região Autónoma da Madeira
RO11	Nord-Vest
RO12	Centru
RO21	Nord-Est
RO22	Sud-Est
RO31	Sud - Muntenia
RO32	Bucureşti - Ilfov
RO41	Sud-Vest Oltenia
RO42	Vest
SI01	Vzhodna Slovenija
SI02	Zahodna Slovenija

Code	*Name*
GR24	Στερεά Ελλάδα
GR25	Πελοπόννησος
GR30	Αττική
GR41	Βόρειο Αιγαίο
GR42	Νότιο Αιγαίο
GR43	Κρήτη
ES11	Galicia
ES12	Principado de Asturias
ES13	Cantabria
ES21	País Vasco
ES22	Comunidad Foral de Navarra
ES23	La Rioja
ES24	Aragón
ES30	Comunidad de Madrid
ES41	Castilla y León
ES42	Castilla-La Mancha
ES43	Extremadura
ES51	Cataluña
ES52	Comunidad Valenciana
ES53	Illes Balears
ES61	Andalucía
ES62	Región de Murcia
ES63	Ciudad Autónoma de Ceuta
ES64	Ciudad Autónoma de Melilla
ES70	Canarias
FR10	Île de France
FR21	Champagne-Ardenne
FR22	Picardie
FR23	Haute-Normandie
FR24	Centre
FR25	Basse-Normandie
FR26	Bourgogne
FR30	Nord - Pas-de-Calais
FR41	Lorraine
FR42	Alsace
FR43	Franche-Comté
FR51	Pays de la Loire
FR52	Bretagne
FR53	Poitou-Charentes

Code	*Name*
SK01	Bratislavský kraj
SK02	Západné Slovensko
SK03	Stredné Slovensko
SK04	Východné Slovensko
FI13	Itä-Suomi
FI18	Etelä-Suomi
FI19	Länsi-Suomi
FI1A	Pohjois-Suomi
FI20	Åland
SE11	Stockholm
SE12	Östra Mellansverige
SE21	Småland med öarna
SE22	Sydsverige
SE23	Västsverige
SE31	Norra Mellansverige
SE32	Mellersta Norrland
SE33	Övre Norrland
UKC1	Tees Valley and Durham
UKC2	Northumberland and Tyne and Wear
UKD1	Cumbria
UKD2	Cheshire
UKD3	Greater Manchester
UKD4	Lancashire
UKD5	Merseyside
UKE1	East Yorkshire and Northern Lincolnshire
UKE2	North Yorkshire
UKE3	South Yorkshire
UKE4	West Yorkshire
UKF1	Derbyshire and Nottinghamshire
UKF2	Leicestershire, Rutland and Northamptonshire
UKF3	Lincolnshire
UKG1	Herefordshire, Worcestershire and Warwickshire
UKG2	Shropshire and Staffordshire
UKG3	West Midlands
UKH1	East Anglia
UKH2	Bedfordshire and Hertfordshire
UKH3	Essex
UKI1	Inner London
UKI2	Outer London

Code	Name
FR61	Aquitaine
FR62	Midi-Pyrénées
FR63	Limousin
FR71	Rhône-Alpes
FR72	Auvergne
FR81	Languedoc-Roussillon
FR82	Provence-Alpes-Côte d'Azur
FR83	Corse
ITC1	Piemonte
ITC2	Valle d'Aosta/Vallée d'Aoste
ITC3	Liguria
ITC4	Lombardia
ITD1	Provincia Autonoma di Bolzano/Bozen
ITD2	Provincia Autonoma di Trento
ITD3	Veneto
ITD4	Friuli-Venezia Giulia

Code	Name
UKJ1	Berkshire, Buckinghamshire and Oxfordshire
UKJ2	Surrey, East and West Sussex
UKJ3	Hampshire and Isle of Wight
UKJ4	Kent
UKK1	Gloucestershire, Wiltshire and Bristol/Bath area
UKK2	Dorset and Somerset
UKK3	Cornwall and Isles of Scilly
UKK4	Devon
UKL1	West Wales and The Valleys
UKL2	East Wales
UKM2	Eastern Scotland
UKM3	South Western Scotland
UKM5	North Eastern Scotland
UKM6	Highlands and Islands
UKN0	Northern Ireland

Table 5. Changes from NUTS 2006 to NUTS 2010 at NUTS-2 level

Code 2006	*Code 2010*	*Label*	*Change*	*Explanation (new = old)*
DE41	DE40 (part)	Brandenburg - Nordost	Merged	
DE42	DE40 (part)	Brandenburg - Südwest	Merged	
	DE40	Brandenburg	New region	DE40 = DE41 + DE42
DED1		Chemnitz	Boundary shift	
	DED4	Chemnitz	New region	recalculation by NSI
DED3		Leipzig	Boundary shift	
	DED5	Leipzig	New region	recalculation by NSI
GR11	EL11	Ανατολική Μακεδονία, Θράκη	Code change	EL11 = GR11
GR12	EL12	Κεντρική Μακεδονία	Code change	EL12 = GR12
GR13	EL13	Δυτική Μακεδονία	Code change	EL13 = GR13
GR14	EL14	Θεσσαλία	Code change	EL14 = GR14
GR21	EL21	Ήπειρος	Code change	EL21 = GR21
GR22	EL22	Ιόνια Νησιά	Code change	EL22 = GR22
GR23	EL23	Δυτική Ελλάδα	Code change	EL23 = GR23
GR24	EL24	Στερεά Ελλάδα	Code change	EL24 = GR24
GR25	EL25	Πελοπόννησος	Code change	EL25 = GR25

Code 2006	*Code 2010*	*Label*	*Change*	*Explanation (new = old)*
GR30	EL30	Αττική	Code change	EL30 = GR30
GR41	EL41	Βόρειο Αιγαίο	Code change	EL41 = GR41
GR42	EL42	Νότιο Αιγαίο	Code change	EL42 = GR42
GR43	EL43	Κρήτη	Code change	EL43 = GR43
GRZZ	ELZZ	Extra-Regio NUTS 2	Code change, label change	ELZZ = GRZZ
ITD1	ITH1	Provincia Autonoma di Bolzano/Bozen	Code change, label change	ITH1 = ITD1
ITD2	ITH2	Provincia Autonoma di Trento	Code change, label change	ITH2 = ITD2
ITD3	ITH3	Veneto	Code change	ITH3 = ITD3
ITD4	ITH4	Friuli-Venezia Giulia	Code change	ITH4 = ITD4
ITE4	ITI4	Lazio	Code change	ITI4 = ITE4
ITE1	ITI1	Toscana	Code change	ITI1 = ITE1
ITE2	ITI2	Umbria	Code change	ITI2 = ITE2
ITD5		Emilia-Romagna	Boundary shift	
	ITH5	Emilia-Romagna	New region	recalculation by NSI
ITE3		Marche	Boundary shift	
	ITI3	Marche	New region	recalculation by NSI
FI13	FI1D (part)	Itä-Suomi	Merged	
FI1A	FI1D (part)	Pohjois-Suomi	Merged	
	FI1D	Pohjois- ja Itä-Suomi	New region	FI1D = FI13 + FI1A
FI18		Etelä-Suomi	Split	
FI18 (part)	FI1B	Helsinki-Uusimaa	New region	FI1B + FI1C = FI18, recalculation by NSI
FI18 (part)	FI1C	Etelä-Suomi	New region	FI1B + FI1C = FI18, recalculation by NSI
UKD2		Cheshire	Boundary shift	
	UKD6	Cheshire	New region	recalculation by NSI
UKD5		Merseyside	Boundary shift	
	UKD7	Merseyside	New region	recalculation by NSI

Table 6. Changes from NUTS 2010 to NUTS 2013 at NUTS-2 level

Code 2010	*Code 2013*	*Label*	*Change*	*Explanation (new = old)*
EL11	EL51	Ανατολική Μακεδονία, Θράκη	Code change	EL51 = EL11
EL12	EL52	Κεντρική Μακεδονία	Code change	EL52 = EL12
EL13	EL53	Δυτική Μακεδονία	Code change	EL53 = EL13
EL21	EL54	Ήπειρος	Code change	EL54 = EL21
EL14	EL61	Θεσσαλία	Code change	EL61 = EL14
EL22	EL62	Ιόνια Νησιά	Code change	EL62 = EL22
EL23	EL63	Δυτική Ελλάδα	Code change	EL63 = EL23
EL24	EL64	Στερεά Ελλάδα	Code change	EL64 = EL24
EL25	EL65	Πελοπόννησος	Code change	EL65 = EL25
FR91		Guadeloupe	Boundary shift	
	FRA1	Guadeloupe	New region	recalculation by NSI
FR92	FRA2	Martinique	Code change	FRA2 = FR92
FR93	FRA3	Guyane	Code change	FRA3 = FR93
FR94	FRA4	La Réunion	Name change	FRA4 = FR94
	FRA5	Mayotte	New region	
SI01		Vzhodna Slovenija	Boundary shift	
	SI03	Vzhodna Slovenija	New region	recalculation by NSI
SI02		Zahodna Slovenija	Boundary shift	
	SI04	Zahodna Slovenija	New region	recalculation by NSI
UKI1		Inner London	Split	
UKI1 (part)	UKI3	Inner London - West	New region	UKI3 + UKI4 = UKI1, recalculation by NSI
UKI1 (part)	UKI4	Inner London - East	New region	UKI3 + UKI4 = UKI1, recalculation by NSI
UKI2		Outer London	Split	
UKI2 (part)	UKI5	Outer London - East and North East	New region	UKI5 + UKI6 + UKI7 = UKI2, recalculation by NSI
UKI2 (part)	UKI6	Outer London - South	New region	UKI5 + UKI6 + UKI7 = UKI2, recalculation by NSI
UKI2 (part)	UKI7	Outer London - West and North West	New region	UKI5 + UKI6 + UKI7 = UKI2, recalculation by NSI

8.5 EXAMPLE OF A RHOMOLO-V2 SAM

Table 7: Reconstructed SAM of LU00 region for 2010.

	2010	LU00																		
	Agricul	Manu Con	TrTrade	BusServ	OthServ	RnD	Kap	Lab_L	Lab_M	Lab_H	Lab RnD	Tax Lab_L	Tax Lab_M	Tax Lab_H	Tax-Prod	House-holds	Govern-ment	Investor	Exp-EU	Exp-RoW
Agricul	54.0	309.6	72.7	4.1	2.2											363.1	0.0	2.8	184.2	9.8
ManuCon	123.4	6256.8	2415.4	1277.8	1162.8											8614.5	238.3	6203.9	9136.3	2659.7
TrTrade	185.4	5851.8	2231.9	2271.4	178.9											1991.9	121.7	0.0	2216.4	4242.0
BusServ	12.7	2810.1	4587.6	44721.1	802.9											3424.6	73.9	478.5	6526.1	39620.6
OthServ	9.3	37.3	84.4	123.4	402.1											1609.8	6413.8	20.0	786.3	4.8
RnD	0.4	221.5	302.8	582.2	56.8															
Kap	145.2	1252.5	3813.8	10841.4	1142.2															
Lab_L	8.6	965.9	706.3	489.4	358.3															
Lab_M	34.3	1349.6	1493.1	1766.6	1576.5															
Lab_H	6.4	841.8	934.0	2878.4	2257.1															
Lab_RnD						1163.7														
Tax-Lab_L	1.3	168.7	98.4	69.2	66.4															
Tax-Lab_M	5.2	232.9	209.9	248.5	293.4															
Tax-Lab_H	1.0	144.5	130.1	559.9	429.1															
Tax-prod	-90.0	2364.9	-71.8	2046.8	44.5															
Households							16398.2	2694.5	6480.2	7185.3	1163.7						-3891.5			2085.0
Government							797.0					404.0	989.9	1264.6	4294.3	5186.0				
Savings																10231.8	9979.6		16199.1	-29705
Imp-EU	289.5	9264.2	1681.6	23393.9	419.1															
Imp-RoW	215.6	6016.9	601.2	11784.0	298.9															

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